A REVIEW OF SELECTED USAF
LIFE CYCLE COSTING MODELS

THESIS

Mark G. Twomey, Flight Lieutenant, RAAF

AFIT/GLM/LSY/91S-66

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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Mark G. Twomey, B.Bus.

Flight Lieutenant, RAAF

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Preface

The primary purpose of this research effort was to make an assessment of the present state-of-the-art in Air Force life cycle cost modeling, and suggest future directions for improvement in the technique. The study was approached by first investigating the history of life cycle costing in the DOD and USAF, to identify the basis and rationale for the method, and then conducting a review of 11 "mainstream" life cycle costing models currently being used by the Air Force.

This study could not have been completed without the assistance of a number of people. Firstly, I would like to thank my thesis advisor, Dr Leroy Gill, for his guidance and assistance in helping to develop a structure for this research effort. Next, I would like to express my appreciation to the numerous cost analysts and operations research personnel at AFLC and AFSC who took the time to share their knowledge and experience of particular LCC models with me. Particularly noteworthy of mention was the assistance provided by Mr Fred Conway of ASD/ALT, and Mr Steve Klipfel of AFLC/FMC. These two gentlemen took time out on numerous occasions to offer me the benefit of their extensive experience in the area of life cycle costing.

Last, but by no means least, I would like to thank my wife, Geniene, and my two children, Nathan and Jacqueline, for their patience and consideration over the last couple of months.

Mark G. Twomey

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Abstract

This study examined the history of the development of life cycle costing (LCC) in the DOD and USAF, and reviewed 11 "mainstream" LCC models currently being used by the Air Force including the LSC, LCCH, ZCORE, CASA, PRICE H, PRICE HL, PRICE M, PRICE S, MLCC, Dyna-METRIC, and LCOM models. A literature search revealed that the last comprehensive reviews of LCC modeling in the USAF were conducted in the 1970s by the Joint AFSC/AFLC Commanders' Working Group on LCC and Rand. LCC's initial development, in the 1960s, was prompted by rapid increases in operating and support (O&S) costs as a percentage of the DOD budget. However, despite regulatory efforts, LCC did not gain equal status with performance and schedule in acquisition programs until the 1980s. The review of LCC models revealed that a number of problems identified by JCWG and Rand during the 1970s still existed. Principally, the problem of gathering data for LCC analyses is still a major concern, both in relation to the validity of the data gathered and the time taken to collect necessary information. The study also identified a number of challenges facing LCC modeling in the future, including the need to coupe with advances in manufacturing technology, adapt to demand-based estimating requirements, integrate the application of LCC models, incorporate expert systems, and establish model validation guidelines.

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I. Introduction

General Issue

Life cycle costing (LCC) is a technique that aims to bring "total cost visibility" to a purchasing program by considering the costs involved in each of the four phases of a system's life cycle- research and development, acquisition operation and support, and disposal (7:5). In order to aggregate costs across the various phases of the life cycle, LCC models are usually employed. A LCC model consists of a systematic set of equations which use cost related variables to derive estimates of system cost drivers. and thereby arrive at a total system LCC (10:11).

The purpose of this thesis is to describe the history of LCC analysis in the USAF (and DOD), evaluate the present state-of-the-art in terms of LCC model development, and suggest future directions and improvements in LCC analysis. Subsequent to this thesis research, it is hoped that the analysis will make possible an assessment of the applicability of various "mainstream" USAF LCC models for use in the Royal Australian Air Force (RAAF).

Background

The USAF has given serious consideration to LCC in major weapon system procurements since the early 1970s when DODD 5000.1 (Acquisition of Major Defense Systems) was first published. Prior to that time, in the mid 1960s, trial LCC equipment procurements had been undertaken after a study by the Logistics Management Institute (LMI) highlighted the shortsightedness of focusing on acquisition costs alone.

During the intervening 20 years LCC methodology and analysis techniques have evolved considerably and undergone substantial refinement in response to changing defense and political needs. Since the inception of LCC analysis to evaluate competing weapon system alternatives, LCC models have been the primary estimating tool used by cost analysts.

Advances in computer technology during the 1980s precipitated a large scale migration of LCC models from mainframe and minicomputers to the microcomputer level, as the memory capacities and data manipulation speeds of the later improved dramatically. This migration, in addition to improving the accessibility of LCC models to cost analysts, also directly contributed to the proliferation of LCC models as users modified code to suit the specific needs of projects under evaluation. The ever increasing size of the Defense Logistics Studies Information Exchange (DLSIE) model catalogue bears testimony to this fact.

Scope of Research

In order to limit the scope of this research effort, only 11 mainstream LCC models currently being used by the USAF were chosen for review. Specific issues considered included the purpose and history of the models, data sources, their cost to maintain and use, perceived benefits and shortcomings of their operation, and the manner in which they are improved and validated.

Plan of Thesis

The primary objective of this research effort is to make an assessment of the present state-of-the-art in Air Force LCC models and suggest future directions for improvement.

Chapter two of this thesis provides an overview of the history of LCC development in the DOD and USAF, describing how the need for LCC was first identified, and detailing the history of regulations and requirements to use LCC. The chapter also describes how the related issues of design to cost (DTC), reliability analysis, and warranty cost benefit analysis (CBA) encompass LCC concepts. Chapter two also identifies the different types of LCC models in use in the USAF today and describes the various circumstances in which they are used. Finally, the chapter describes the offices which are currently using LCC, when they are using it, and the decisions being made based on LCC analysis results.

Chapters three, four and five provide a review of the 11 LCC models. The models have been grouped according to the phase or phases of the life cycle on which they concentrate. Chapter three provides details on the Logistics Support Cost (LSC) model, the Life Cycle Cost H (LCCH) model and the personal computer (PC) version of the Cost Orientated Resource Estimating (CORE) model. These models focus, principally, on the operation and support (O&S) phase of an equipment's life cycle. In contrast, the models reviewed in chapter four provide more extensive coverage of an equipment's life cycle, including the research and development, acquisition, and operating and support phases. The models include the Cost Analysis and Strategy Assessment (CASA) model, the Parametric Review of Information for Costing and Evaluation (PRICE) family of models, and the Modular Life Cycle Cost (MLCC) model. Lastly, chapter five provides details on two models which are not normally classified as LCC models; the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) model, and the Logistics Composite (LCOM) model. These models are included in the review because of their ability to provide significant input to LCC analyses.

Issues examined for each of the models selected include their purpose and development history; data requirements; strengths and shortcomings; the costs and benefits of model use; and the manner by which they are improved and validated.

Finally, chapter six provides a summary of the research findings and makes recommendations for improvements, both present and future, in the use of LCC models.

II. Literature Review

Chapter Overview

This chapter provides an overview of LCC modeling. It begins by defining the key terms used in association with LCC. Next, a chronology of the development and use of LCC in the DOD and USAF is presented to give the reader some background on how LCC has evolved over the years. Following this, a discussion on the broad uses and applicability of LCC in defense procurement is presented. The different types of LCC models and their applications are then described, and finally, the current use of LCC in the USAF is investigated. Also included in this chapter is a description of the offices involved in LCC management and analysis in the USAF, and the role played by LCC in the weapon system acquisition process.

Definition of Terms

Life Cycle Cost (LCC). AFR 800-11, Life Cycle Cost Management Program, states that LCC is "the total cost to the government for a system over its full life" (43:1). Sims identifies the phases of LCC in her definition; "life cycle cost is the total cost to the government of acquiring, operating, supporting and disposing of a system over its lifetime" (145:12). Sims also identifies the objective of life cycle costing as an attempt to lower a system's LCC "by striking a balance between acquisition and O&S costs"

(145:12). Typically, the life of a system is broken down into four parts or periods: research and development, production, operating and support, and disposal (43:1; 124:Ch 2,1). Emmelhainz notes that the O&S phase is typically the longest and most costly phase of the system's life cycle (68:36).

Blanchard believes that the objective of LCC is to bring "total cost visibility" to an acquisition program (7:5). He argues that "the bulk of total system costs are <u>not visible</u>" (7:4), particularly the costs associated with the operational use of a system, maintenance and logistics support, and retirement and disposal (7:4). Blanchard relates the cost visibility problem to the "iceberg effect" illustrated in Figure 1 (7:6). The diagram shows that only the acquisition costs of a system are readily apparent, but the manager must consider the "submerged" support costs if major problems are to be avoided.

<u>Life Cycle Cost Management (LCCM)</u>.

> LCCM is a cost management discipline used in managing a product throughout its life cycle. It involves the consideration of current and future cost consequences, such as life cycle cost or applicable segments thereof, along with performance, schedule, and supportability aspects, in making decisions affecting the acquisition and follow-on support of the product. It requires a cost conscious attitude and a plan for reducing or controlling costs. (43:1)

<u>Life Cycle Cost Models</u>. LCC models are sets of systematic equations which use system cost drivers in order

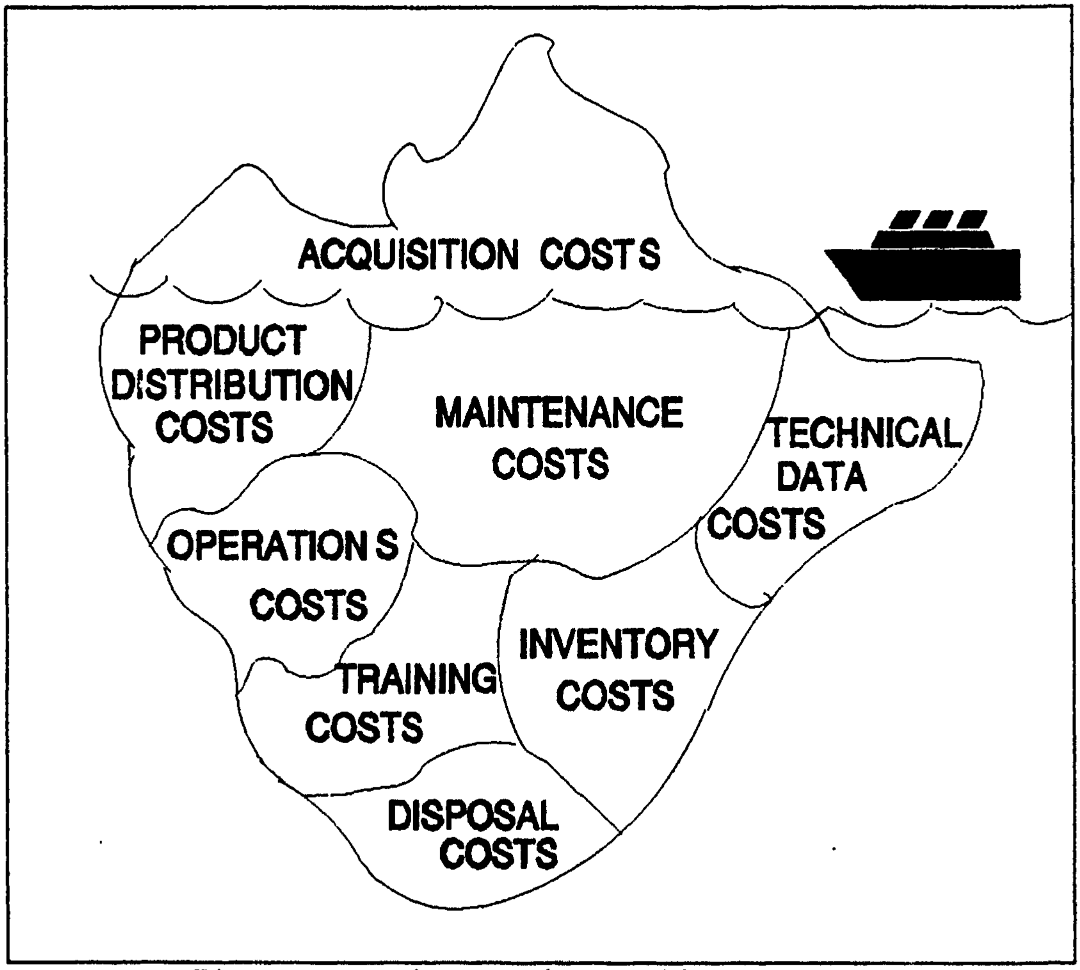

Figure 1. The "Iceberg Effect" (7:6)

to calculate LCCs. The models may be simple or highly complex (7:81; 124:Ch 1,2).

Cost Element Structure. The cost element structure is the framework upon which an LCC model is built. The cost elements are structured to accumulate the total LCCs for a system or subsystem. An example of one piece of the overall framework might be unit level consumption, which has as its

cost element components petroleum, oil, lubricants, maintenance material, and training ordnance (124:Ch 4,3).

Cost Estimating Relationships (CERs). CERs are normally mathematical equations which yield the costs of a specific cost element. Blanchard describes CERs as "basically 'rules of thumb' which relate various categories of cost to cost generating or explanatory variables of one form or another" (7:38). CERs are usually derived from historical data using statistical regression techniques.

A more complete list of LCC related terms is provided at Appendix A.

History of LCC in DOD and USAF

The 1960s--the Emergence of LCC. Although it seems obvious today that one should consider the total ownership cost or LCC of a weapon system when considering its procurement, the situation was not always as apparent to the DOD acquisition community. During the 1950s the primary emphasis in procurement was on system performance and production schedule. Powers and Recktenwalt suggest that this emphasis was brought about by the Soviet Union's orbiting of the SPUTNIK satellite in 1957. The event caused a technological shock in the United States and resulted in the country entering a technology race with the USSR (135:12). Powers and Recktenwalt believe that the perceived threat to US national security "provided the impetus for a

change in our [US] acquisition philosophy from 'fly before buy' to concurrency" (135:12). Under this philosophy, time was the driving mechanism and cost became a secondary issue. The major defects of the philosophy were higher unit production costs and the need, because of the rapid pace of system development, to find post-production solutions to designed-in defects (135:42). Rapid advances in technology led to increased performance but the accompanying rise in system complexity caused decreased system reliability and led to a rapid growth in O&S costs.

In the mid 1960s, Recktenwalt notes, elements of the DOD realized that "the percentage of total financial resources consumed by O&S was increasing rapidly and soon would surpass the percentage available for acquisition of new weapon systems" (137:1). If the trend continued, Recktenwalt suggested, "the DOD would ultimately expend all its resources supporting existing weapons systems and have no funds to develop new ones" (137:1). In 1968, for the first time, the O&S portion of total weapon systems costs exceeded 50 percent of the DOD budget (135:29-30). Powers and Recktenwalt note that:

> the concurrency concept was used as an acquisition philosophy up until the early 1970s when the cost growth of new Air Force weapon systems caused a reappraisal of our [US] acquisition philosophy by SecDef and Congress. (135:13)

LCC Trial Procurements. It was during the 1960s that emphasis first began to be placed on LCC. In late 1963

the Logistics Management Institute (LMI) was commissioned by the Assistant Secretary for Defense for Installations and Logistics (I&L) to assess the impact of LCC in competitive procurements at the price contract level (59:5). The final LMI report, titled "Life Cycle Costing in Equipment Procurement" was issued in April 1965. Earles notes that it concluded that the use of predicted logistics costs, despite their uncertainty, was preferable to the traditional practice of ignoring logistics costs altogether because their absolute accuracy could not be guaranteed (64:Sec 1,2). Based on the LMI study recommendation, the Assistant Secretary for Defense for I&L initiated a trial LCC program which began in July 1965 (59:78). As Finan notes, "the test program involved nonreparable equipments purchased on a price-per-unit-of-service-life basis rather than merely on the basis of unit price" (71:10). Probably the best know case was of the purchase of aircraft tires. The Government bought tires from a number of perspective contractors, mounted them on aircraft, and measured the average cost per landing. The tire having the lowest total cost per landing was then purchased in bulk (64:Sec 1,2).

At the same time as the nonreparable procurements were taking place, Earles notes that "major new emphasis was placed on logistics support and the reduction of support costs at the system level" (64:Sec 1,2). In 1964, a DOD Directive on Integrated Logistics Support (DODD 4100.35) was

issued which called for the minimization of total system LCCs (64:Sec 1,2). Then, in 1969, DODD 7041.3 (Economic Analysis and Program Evaluation for Resource Management) was published requiring that economic analyses of proposed DOD investments include LCC estimates (64:Sec 1,2).

At the same time as the emergence of LCC, the US became involved in the Vietnam conflict. Because of substantial opposition to the war at home, US media attention focused on the growth of the defense budget and its domestic policy implications. The criticism culminated in several special congressional studies which sought ways to stem defense outlays. Among these studies were the Blue Ribbon Panel and the Congressional Commission on Government Procurement. Earles notes that amongst the key recommendations from these studies "was the application of life cycle costing to system and equipment acquisitions" (64:Sec 1,2).

Resistance to LCC. Despite these initiatives, however, the concept of LCC was slow to gain acceptance in the DOD acquisition community. Seldon suggests several reasons for this inertia (141:4-8):

1. Congressional separation of appropriations for procurement funds and operating and support funds. Because procurement funds are administered separately from O&S funds there are no institutional incentives for the procurement organization "to pay a higher purchase price for an item in

order to decrease later costs for the products operation and support" (141:4).

2. Immediate budget stringencies often cause politicians to focus on short term rather than long term costs. There is a firm belief among congressional members and administrators that the public judges them on their current performance, rather than on the potential benefits resulting from their foresight (141:5).

3. Past procurement policies resembling LCC turned out badly. Seldon suggests that:

> During the 1960s, then Secretary of Defense Robert McNamara (1961-1966) instituted several major 'total package procurements' which incurred widespread criticism for their heavy cost overruns. Total package procurement attempted to contract for the total cost of development and production early in the development cycle and did not explicitly concern itself with later phases, whereas LCC seeks to evaluate (and later contract for) the costs of procurement and operation and maintenance. Despite these crucial differences, LCC has had to bear the onus for the failure of total package procurement. (141:5-6)

4. Doubts about the accuracy and reliability of data and about LCC methodology. Cost data is jealously guarded by contractors and even within the DOD it is hard to obtain because of differing nomenclatures and because databases are designed to support financial accounting activities, not LCC. Also, few LCC models had been developed at that stage, and no standard LCC methodology or cost element structure had been determined to allow the outputs of various models to be compared (10:2).

5. Contractors were reluctant to guarantee estimates unless they could control costs. Critics of LCC argued that no one could predict the behavior of a complex weapon system twenty years into the future or estimate the O&S costs of a new weapon system before it is designed. Additionally, contractors argued that they had no control over military operations and maintenance that could radically alter costs. The situation was deemed too uncertain to expect contractors to assume a significant financial risk. Speculation on cost tradeoffs was seen as an interesting idea for engineers and logisticians but not a basis for contractual arrangements.

In essence, contractors and DOD acquisition personnel had misinterpreted the basic aim of LCC. Seldon notes that "LCC does not require the prediction of the future" (141:8). He suggests that:

> most LCC work involves the comparison of competing systems; anticipated ultimate costs are less important than the assessment of comparative costs of alternative approaches to the problem. Moreover, future changes that diverge from LCC assumptions are likely to affect rival systems equally and are unlikely to reverse the conclusions of an LCC study. (141:8)

<u>The 1970s--Tailoring LCC Methodologies</u>. By the early 1970s the worth and potential of LCC had been recognized, despite opposition. Earles notes that in 1971 the DOD issued its key acquisition policy directive , DODD 5000.1, which "firmly established the requirement for not only life cycle costing, but also, Design to Cost" (64:Sec 1,3). The directive required that the cost of owning and operating a

weapon system be considered when establishing acquisition cost parameters, and that discrete cost elements be translated into 'design to' requirements (64:Sec 1,3). In the same year the USAF issued its "Optimum Repair Level Analysis (ORLA)" manual (AFLCM/AFSCM 800-4) which defined "optimal" equipment levels and repair locations to mean those that result in the lowest LCCs (64:Sec 1,3).

In 1973, the Secretary of Defense implemented the Blue Ribbon Committee's recommendation to improve cost estimating by establishing the Cost Analysis Improvement Group (CAIG) (64:Sec 1,6). The CAIG's primary role was to act as the main advisory body to the Defense Systems Acquisition and Review Council (now the Defense Acquisition Board(DAB)) on matters relating to cost (10:6). Its terms of reference also included the design of a standard cost element structure for weapon systems which could be used in LCC computations (10:1,15). This action was aimed at improving the credibility and comparability of LCC estimates. Earles notes that also in 1973 the Joint Logistic Commanders of the Army, Navy and Air Force issued its initial guide on DTC (64:Sec 1,6). In the same year, in recognition of the growing importance of LCC, the AFLC and AFSC Commanders formed a Joint Working Group on LCC to identify how LCC could best be implemented in the commands, and develop tools and methodologies that could be used "to achieve a more effective consideration of LCCs during the acquisition process" (59:6).

Despite these efforts O&S costs continued to rise, reaching 70 percent of total weapon system costs during 1974 (14:2). Recognizing that the situation had become critical, the DOD issued Directive 5000.28 on DTC in 1975 (64:Sec 1,6). Bennett indicates that DODD 5000.28 "explicitly emphasized management of weapon systems to ensure establishment of 'costs as a parameter equal in importance with technical requirements and schedules'" (5:1). This was the first official policy statement relating DTC and LCC (5:1).

Origins of VAMOSC. Also in 1975, the Assistant Secretary of Defense promulgated Management by Objective nine (MBO 9) with the stated aim of reducing O&S costs. A subset of this memorandum, MBO 9-2, titled "DOD Requirements for Visibility and Management of Support Costs", tasked the military departments to:

1. develop weapon systems O&S cost visibility,

2. develop component level cost visibility,

3. standardize O&S cost terminology and definitions DOD-wide, and

4. institutionalize the O&S cost systems at each service. (137:2)

This memorandum was the genesis of the Visibility and Management of Operating and Support Cost (VAMOSC) database systems that eventually became operational in 1982 (137:5). VAMOSC was established to allow the identification and reporting of historical O&S costs of major defense weapon systems (69:3). The lack of readily available and accurate

O&S costs had been identified as a major impediment to the development of LCC modeling and analysis in a number of LCC related studies (24; 59; 72; 73;).

<u>Congressional Awareness of LCC</u>. Congressional awareness of LCC continued to grow in the late 1970s. Earles notes that in 1978 the Senate Committee on Armed Services requested LCC estimates on programs in its Selected Acquisition Review (SAR)" (64:Sec 1,7). Also in 1978, courses on LCC were established at the Defense Systems Management College and Air Force Institute of Technology (64:Sec 1,7).

<u>LCC Model Development</u>. With the establishment of guidelines and regulations emphasizing LCC in the 1970s, a number of new cost models were developed to assist in LCC analysis and achieved widespread use. Few of the models developed could be considered complete LCC models in the true sense of the concept because, generally, they concentrated on a specific phase in the weapon system life cycle, eg. RD&TE and acquisition, or O&S. A review of available LCC models used by the Air Force by the Joint AFSC/AFLC Commanders' Working Group on LCC in 1975 revealed a number of models, with different capabilities, in frequent use (25). While acknowledging that LCC models could provide valuable guidance on a wide range of program decision issues, the study highlighted a number of deficiencies in the use of existing LCC models. More specifically, models were found to (25:8):

1. be insensitive to weapon system performance and design parameters,

2. be too complex,

3. require data input that frequently could not be provided in a timely manner or with a reasonable level of confidence, and

4. be insensitive to wear-induced failures.

A further appraisal of the use of LCC models in the Air Force was conducted by Rand in 1978. This study identified and reviewed eight aircraft system models that were receiving widespread use during the period. The review, which looked specifically at the models' ability to estimate ownership costs, was critical of a number of perceived model deficiencies. The models were criticized for:

> 1. Inconsistent and often ambiguous definitions of cost elements [which made it hard] to relate model outputs to budgetary or other resource programs...or empirically confirm or refute their reasonableness. (121:2)

2. Insensitivity to important cost driving factors, particularly policy related issues, and "poor representation of causal relationships governing demands and costs of aircraft systems" (121:2).

3. Inadequate distinction between intermediate and final resources demands and their dollar costs (121:2).

4. "Inconsistent treatment of individual cost elements..." (121:2).

Despite the criticisms of these reports LCC models continued to be developed and used on an increasing basis.

The 1980s--Institutionalization of Procedures. Earles has described the 1980s as a period during which the use of LCC techniques and procedures became institutionalized within the DOD (63). LCC models continued to be developed and refined, the main changes being in cost element structure (CES) where the CAIG had established a standard for aircraft systems (10).

The Link Between LCC and RAM. In the 1980s, the link between reliable weapon system performance and lower O&S costs, which had been firmly established during the 1970s, was reaffirmed and re-emphasized by the DOD Acquisition Improvement Program (AIP) initiated by then Deputy Secretary of Defense Frank Carlucci. Cochoy notes that of the 31 areas selected for special attention in the AIP, five concerned reliability, availability and maintainability (RAM) (22:8). The AIP prompted the revision of DODD 5000.1 (Major and Non-Major Defense Acquisition Programs), DODD 5000.39 (Acquisition and Management of ILS for Systems and Equipment) and DODI 5000.2 (Defense Acquisition Program Procedures) to increase the priority of support and readiness (22:8). Cochoy believed that the "revised documents clearly raised readiness and supportability to a level equal in importance to (program) cost, performance and schedule considerations" (22:8). The amended regulations required that readiness

goals be included as part of the design objectives for new systems established at Milestone I (Concept Validation Approval) (22:8). This action was an important step forward in containing the LCCs of weapon systems "since it has been estimated that 70 percent of the LCCs for a system are established as a result of design decisions made prior to DSARC [DAB] Milestone I" (12:8). Cochoy explains that "the earlier in systems design RAM is considered, the greater the LCC leverage that can be expected from expenditure of those RAM funds" (22:9).

Warranty Legislation. Increased emphasis on RAM and lower support costs of weapon systems in the early 1980s is also reflected in a shift in policy towards increased use of warranties to obtain more reliable systems and components (3:9). At the request of Senator Mark Andrews, the 1984 DOD Appropriation Act included a provision making warranties mandatory in production contracts for weapon systems (108:6). This law was superseded by the 1985 DOD Authorization Act (Public Law 98-525) which required that all weapon systems entering production and costing more than $100,000 each or having a total procurement cost greater than $10,000,000 have a warranty unless an OSD waiver was approved (108:6). The law required that weapon system contracts incorporate warranty guarantees relating to (108:6):

1. design conformance and manufacturing requirements,

2. defect levels in workmanship and materials, and

3. essential performance requirements.

Beck indicates that prior to 1984 Government policy had been "not to buy a warranty automatically" although warranty purchase provisions had existed in acquisition regulations since the early 1970s (3:9). In a large number of procurements, inspection and frequent testing of items was preferred to a warranty (3:9).

Air Force Implementation of Warranty Law. The Air Force regulation implementing the warranty law, AFR 800-47 (now AFR 70-11) required that the program office "prepare and coordinate a weapon system warranty (WSW) plan" (108:6) in order to ensure the successful implementation of the warranty. One of the key elements of the WSW plan is the warranty cost benefit analysis (CBA). However, detailed guidance on how to perform a warranty CBA appears to be lacking (112; 150:4). A 1987 GAO report indicated that "many warranties [were obtained] without appropriate cost effectiveness analyses", suggesting that guidelines on conducting warranty CBAs are still inadequate (78:2).

Proliferation of LCC Models. Advances in computer technology during the 1980s enabled the rapid migration of LCC models from mainframe to microcomputers. In addition to improving the accessibility of LCC models to cost practitioners, the migration encouraged the proliferation of

models as individual users sought to modify generic models to suit their particular circumstances.

Strengthening of ICA Function. The 1980s also saw increased emphasis placed on the importance of independent cost analyses (ICAs) prepared for the CAIG and DAB. A ICA is prepared at each program milestone to check the reasonableness of the SPO prepared estimate. The CAIG has been pressing for ICAs earlier in system life cycles than has been customary in the past (92:2). This reflects increased competition for resources as the unit cost of weapon systems continues to rise.

Baselining. An important development relating to LCC that occurred in the second half of the 1980s was "baselining" of selected major weapon systems projects. The requirement for baselining is detailed in DODD 5000.45 (Baselining of Selected Major Systems) which was issued in August 1986. It is described in DODD 5000.45 as "a technique used to enhance stability and control cost growth of selected major programs" (51:1). Essentially, a program baseline is a formal agreement between a Program Manager (PM) and a Program Executive Officer (PEO), Service Acquisition Executive (SAE) or the Defense Acquisition Executive (DAE) that briefly summarizes factors critical to the success of a program, such as functional specification, cost and schedule objectives and requirements against which the program will subsequently be evaluated.

The PM is responsible for preparing the baseline document and updating it at milestone decision points. The baseline is treated as being fixed and the PM is responsible for ensuring that his program stays within the established baseline. Only the DAE can approve a baseline variation (51:2-3). The importance of baselining, as far as LCC is concerned, is that it unequivocally elevates the cost of weapon system ownership to the same status as system performance, schedule and acquisition cost in the eyes of the PM. Despite previous regulatory efforts which clearly established readiness and supportability on an equal footing with these parameters, the main impediment to the effective application of LCC techniques remained the fact that PMs continued to be rewarded for going for as much performance as possible and allowing for a pre-planned production improvement program later on to improve logistics supportability (22:9).

DTC Military Standards. LCC received further emphasis in the late 1980s with the publication of MIL-STD-337 (Design to Cost). The MIL-STD. and its associated handbook (MIL-HDBK-766) and data item descriptions (DI-MISC-80856 and DI-MISC-80857), provided general and specific guidance on how to achieve baseline cost targets. The principal tool identified in MIL- TD-337 for realizing the cost targets is the DTC Program. The DTC Program stresses the requirement for making LCC "elements inherent in the

critical functional areas of reliability, logistics, and optimization by using tradeoff studies, cost estimation and tracking in the life cycle management acquisition process" (56:1). The MIL-STD indicates that the contractor's DTC program should include (56:4):

1. identifying cost drivers, developing cost targets and conducting tradeoffs of candidates from a selected list of cost drivers to determine the most cost effective alternatives;

2. monitoring cost targets, documenting progress and resolving problems; and

3. controlling relevant LCCs through implementing feedback techniques during the design process.

Additionally, MIL-STD-337 provides guidance to contractors on the use of LCC models and methodologies in cost analyses during the various phases of the acquisition process, and also details data reporting requirements (56:19-20,25). The standard handbook describes how incentives, including warranties, should be used to motivate contractors to achieve a product that can be produced and supported at or below DTC targets (55:32).

<u>Cost and Operational Effectiveness Analyses</u>. The most recent development affecting LCC was the establishment of the requirement, in the late 1980s, to conduct a cost and operational effectiveness analysis (COEA) at each milestone, from one onwards, in major weapon system procurements (113).

As mentioned previously, DODD 5000.45 (Baselining of Selected Major Systems) had unequivocally elevated LCC to the same status as schedule and performance in the management of DOD procurements. However, in essence, these three key variables continued to be treated separately as there was no formal requirement to conduct cost-schedule-performance tradeoff studies. This anomaly was remedied when DODI 5000.2 (Defense Acquisition Management Policies and Procedures) was revised. The new instruction required that trade-off analyses be conducted as part of the COEA.

Conclusion. LCC has undergone considerable evolution since its applicability to DOD purchases was first recognized back in the early 1960s. During the late 1960s and 1970s increased emphasis was given to the concept by the USAF as the O&S cost of weapon systems continued to spiral. During the period, a substantial number of LCC models were developed for specific applications and LCC regulations and methodologies continued to be refined. The 1980s can aptly be described as a time when LCC became institutionalized. The concept's link to DTC and RAM was firmly established during the period and it became an integral part of major weapon system procurement considerations.

Types of LCC Models

Collins' Classification Scheme. The review revealed several different LCC model classification schemes. For

instance, Collins groups the types of models used by the Air Force into three general categories:

1. cost factor,
2. accounting, and
3. optimizing (26:54).

<u>Cost Factor Models</u>. Cost factor models, based on Air Force-derived cost factors, are used to compute weapon system O&S cost estimates. The estimate is the sum of cost elements achieved by multiplying the derived cost factors by parameters like flying hours, number of weapons purchased, or flyaway cost of the new system. The model is easy to use, but reflects only the system cost elements and not the subsystem cost elements. Collins observes that:

> by not explicitly breaking out costs in detail at the subsystem and line-replacement unit level (LRU) level, this approach tends not to capture the O&S cost impact of peculiar reliability and maintainability (R&M) characteristics of a new weapon system. (26:55)

<u>Accounting Models</u>. Accounting type models are more complicated than cost factor models, but are used to a greater extent. This type of model allows O&S costs to be computed at the LRU level. The costs of these elements/components (eg. initial and replenishment spares costs, on- and off-equipment maintenance costs) are then summed to compute the total O&S costs of the system. To accomplish this low level visibility four categories of input parameter estimates are needed:

1. program elements,

2. contractor-furnished subsystem elements,

3. contractor-furnished LRU elements, and

4. Air Force-furnished constant elements (26:55).

Collins believes that parametric cost models, which are based on cost-estimating relationships (CERs), are a category of accounting type models. This type of model uses easily quantified variables, like size and weight, to estimate more qualitative variables such as production schedule, or more complex quantitative variables such as total system LCC. Krisch notes that "The key feature of a parametric model is its ability to be calibrated (or tuned) to specific empirical values obtained through the study of similar or analogous situations in the past" (114:1527-28). May believes that "A CER is simply a mathematical equation that relates one or more characteristics of an item to a desired element of cost" (124:Ch 3,1). Additionally, May relates that early in a program CERs may be the only tool available, and, despite the difficulty in developing them, their application is straight forward (124:Ch 3,3-5).

The disadvantages of accounting models relate to the detailed breakdown of information they need to operate. The requirement for a large amount of data brings with it the potential problem of standardization. Additionally, validation of the large amount of input data becomes a concern (26:56-57). The work of the Cost Analysis Improvement Group (CAIG) has assisted in the standardization

of input data. However, the data validity problem is more difficult to overcome. The F-16 program, for instance, reduced the number of cost areas down to six to alleviate the difficulty. These represented the majority of the system costs. This adjustment enabled validation of the input data at the expense of some loss of information (26:57).

Optimizing Models. Optimizing models try to maximize across a subset of support alternatives in order to minimize O&S costs. The single item-single indenture model is an example of an optimizing type model. The model is easy to use, like the cost factor type models. When applied to LRUs, Collins notes that:

> it simply adds up the various costs of each of three maintenance alternatives (levels of repair) for a given LRU--discard at failure, repair at base and repair at depot--and identifies the least cost of the three policies. (26:57)

The main limitations of this type of model are the requirement for an allocation procedure and the lack of capability to cost out repairs below the LRU level (26:57-58).

JCWG Classification Scheme. The Joint AFSC/AFLC Commanders' Working Group (JCWG) on LCC, on the other hand, notes that LCC models may be broken down into ten categories:

> 1. Cost Factor Model - A model in which each cost element is estimated by multiplying a key weapon system parameter by a factor which is derived as a function of Air Force cost experience on similar weapon systems.
>
> 2. Accounting Model - A set of equations which are used to aggregate components of support costs,

including costs of manpower and material, to a total or subtotal of life cycle costs.

3. Cost Estimating Relationship (CER) Model - A statistically derived set of equations each of which relates LCC or some portion thereof directly to parameters that describe the design, performance, operation, or logistics environment of a system.

4. Economic Analysis Model - A model characterized by consideration of the time value of money, specific program schedules and the question of investing money in the near future to reduce costs in the more distant future.

5. Logistic Support Cost Simulation Model - A model which uses computer simulation to determine the impact of an aircraft's flying program, basing concept, maintenance plan, and spare and support resource requirements on logistic support cost.

6. Reliability Improvement Cost Model - A set of equations that reflects the costs associated with various increments of improvement in equipment reliability.

7. Level of Repair Analysis Model - A model that, for a given piece of equipment, determines a minimum cost maintenance policy from among a set of policy options that typically include discard at failure, repair at base, and repair at depot.

8. Maintenance Manpower Planning Model - A model that equates the cost impact of alternative maintenance manpower requirements or the effects of alternative equipment designs on maintenance manpower requirements.

9. Inventory Management Model - A model that determines, for a given system, a set of spare part stock levels that is optimal in that it minimizes system spares costs or minimizes the Not Mission Capable Supply (NMCS) rate of the system.

10. Warranty Model - A model that assesses the relative costs of having the Government do in-house maintenance versus having this maintenance performed by contractors under warranty. (23:7-8)

The ten categories described above seem to be more descriptive and possibly more comprehensive than the three

provided by Collins. Cost factor models are common to both groups and the accounting categories are roughly equivalent, except that the JCWG separates out CER models, whereas Collins groups them together. Optimizing models and level of repair analysis models are equivalent. The remaining six categories identified by the JCWG are difficult to place into the three more general categories of Collins.

Previous Model Evaluation Studies

The literature review revealed that despite the fact that there are a large number of LCC models in use in the USAF very few evaluation or validation studies have been done. This is surprising, particularly in view of the fact that the most comprehensive evaluation effort undertaken to date, a study conducted by the Rand Corporation in 1978, found that "considerable uncertainty exists about the efficacy of life cycle cost analysis as a management tool" (122:v). In the study, RAND evaluated a number of "main stream" models used in the estimation of aircraft systems. They concluded that there were few areas where the models reviewed were capable of producing reliable estimates of the absolute costs of proposals and many areas where the models provided no useful cost estimating capability (122:vii). Earlier, in 1975, the JCWG had looked at a "representative set" of general and specific purpose LCC models in making an assessment of the availability of models for LCC analysis in

the Air Force (25:3). Models in eight different categories were examined in the review (25:3). While concluding that LCC models could provide valuable guidance on a wide range of program decision issues, they noted four common model deficiencies (25:8):

1. They were not sensitive to performance and design parameters.

2. They were generally too complex to be used without special training, particularly the general purpose models.

3. Their requirements for input data frequently could not be fulfilled because the models needed extensive input data or input data was not compatible with available historical data.

4. They were not sensitive to wear-induced failures.

Several other studies have also looked at the LCC model validity issue. In the 1970s, Cavender (15) and later Clark (20) evaluated the ABLE O&S cost model, which was used for the A-10 Close Support Aircraft. The reviews were undertaken because the A-10 aircraft project was the first major USAF weapon system to make use of LCC (33:14). Both authors concluded that the ABLE model was valid. In 1977, Large and Gillespie (116) examined a sample of seven parametric aircraft airframe cost models that had been developed for the USAF by several private contractors over the period 1965 to 1977. Their aim was to determine whether model outputs were reasonable over a broad range of inputs (116:v). They

concluded that all the models had deficiencies and all should be used with caution. They also suggested that cost analysts should calibrate models against their own experience and noted that "no model should be used uncritically" (116:47). In 1980, Hernandez undertook a validation study of the OSCATE avionics LCC model. Earlier, Bell and Turney (4), and Davis and Wysowski (33), had studied the application of LCC techniques in the A-10 and F-16 weapon system acquisition projects. However, in both cases, the authors assumed that the O&S cost models used during the projects were valid and no specific assessment of their reliability was made.

The most recent validation study was completed on the AFLC LSC model in May 1990. This investigation, which was undertaken by a civilian contractor, involved a detailed examination of the algorithms used in the model and their underlying assumptions. This study concluded that the structure of the LSC model and its equations were basically sound (1).

The number of model validation studies is likely to increase in the future owing to the fact that the CAIG has recently decreed that only validated models may be used to prepare estimates for DAB submission (39).

Problems Encountered. The evaluation efforts of the Rand investigators in 1978 were essentially qualitative in nature, and involved a subjective assessment of the models' ability to predict the effect (if any) on a cost element of a

change in the relevant cost driving factor (122:v). They found that more than half of the relevant "driving factor/ cost element combinations" were either not dealt with by the models reviewed or were handled in a manner that appeared completely unrelated to the real cause and effect relationship (122:vii). The Rand study found that historical data needed in support of LCC estimates was difficult to find. This they attributed to incompatibility between the cost categories used in LCC models and the functional accounting categories used to record manpower and cost information (122:vii). Hernandez found a similar problem in his 1980 study of the OSCATE model. He was unable to determine the prediction accuracy of the model because the historical data needed for comparison purposes was recorded in aggregate form and could not be separated into specific cost element components (95:66).

Data limitations are also causing problems for parametric aircraft cost models. Daniel notes that the lengthening period between major aircraft projects is inexorably eroding the database used to generate CERs (32:7). Also, he suggests, "new technology threatens to provide the revolutionary discontinuity that will ruin the parametric extrapolation so often used by cost estimators" (32:7). Similarly, Johnson notes that parametric models have difficulty estimating projects which advance the state-of-the-art "since by definition there is usually no historical

data upon which to base the estimates" (109:26). Technology complexity indexes have been introduced into CERs in an attempt to overcome the problem, but, so far, have meet with little success (109:26; 96; 101). The Rand study also commented on how the lack of a uniform, well defined cost element structure for model input made it difficult to compare the forecast costs of different models (122:vii). This is particularly important since any weapon system proposal presented to the Defense Acquisition Board (DAB) must have at least two different estimates prepared; one by the program office, and the other by an independent organization which is usually the cost analysis staff group from within the product division. RAND argued that a single methodology is needed that will generate compatible estimates for all O&S elements (122:vii).

Possible Solutions. The methodology problem identified by Rand has largely been overcome since the time of their study by the CAIG publication of standard cost element structures for weapon systems. Most LCC models have either been converted, or are in the process of being converted, to CAIG format (10:7). In relation to the availability of O&S historical cost data, a new data collection system has been introduced since Rand and Hernandez encountered their difficulties. It is the Visibility and Management of Operating and Support Costs (VAMOSC) system. VAMOSC is an automated, relational data base system that has been designed

to gather virtually all O&S cost data on certain Air Force systems and make them available to users in flexible formats (17:148).

Model Assessment Criteria

The literature was also reviewed in an attempt to identify a suitable set of model evaluation criteria. In this context, validity is "a measure of how well the model represents the real world environment in question" (33:17). The validity of a model is usually gauged by comparing the projected cost forecast by the model against the actual cost experienced. Additionally, the model is usually examined to ensure that costs are derived in a logical manner and are consistent throughout the model. Although validity is a necessary pre-condition, it is not sufficient, by itself, to guarantee a model's usefulness and appli ability. The Joint AFSC/AFLC Commanders' Working Group (JCWG) on LCC suggested that there are several other desirable model characteristics (88:16-19). These characteristics include:

> 1. Completeness. A model should include all elements of cost appropriate to the decision issue under consideration. If a total life cycle cost estimate is needed for planning or budgetary purposes, the model must include essentially all elements of program cost. However, when the decision under consideration does not affect all the cost elements, only those elements affected by the decision may need to be considered in the cost model used for analysis of that particular decision.
>
> 2. Sensitivity. To be useful in design trade studies and other decisions, the model used must be sensitive

to the specific design of program parameters being studied, so that cost differences between the alternatives can be determined. Although this characteristic appears obvious, it remains a significant problem since many LCC models do not include design and performance parameters associated with systems and equipment found in the Air Force. This problem becomes further aggravated by the fact that many types of Air Force systems have unique design and performance characteristics which may require different models so that design trade[-off] studies can be conducted when alternatives are being considered.

3. Availability of Input Data. In order for any cost model to be useful, it must be feasible to obtain accurate input data for the model. In some cases, otherwise good cost models are of questionable value since accurate input data is not available. In other cases, the input data may in fact be accurate but not readily available causing extreme workloads to be placed upon personnel attempting to collect the data.

4. Documentation. Since cost models can differ radically in their approaches to determining life cycle costs there must be adequate model descriptions so that work can quickly be reviewed and understood by others. Analysis methods and assumptions must be documented and readily available to analysts. (88:16-19)

Drobot notes that although all of the above characteristics are important when assessing a model's overall usability, some are more important than others. He weighted the criteria to make validity the most important characteristic, followed by availability of data, completeness, sensitivity and documentation, in that order (61:11-12).

Defense Acquisition Process

LCC is used in some way by just about every Air Force organization involved in the acquisition and support of military hardware and software. Owing to the fact that LCC

and the Air Force acquisition process are inextricably linked, a brief review of the acquisition process is in order.

Basis. The DOD acquisition process is a needs based system, i.e., all acquisition programs are based on identified mission needs. A mission need generally revolves around a requirement to counter a perceived threat to national security by developing a new operational capability or improving an existing capability. However, it may also involve an opportunity to reduce the ownership costs of a existing weapons system (54:Pt 3,1). The mission need is formally documented and expressed in terms of a specific operational capability requirement in the Mission Need Statement (MNS). It is the MNS that initiates the acquisition process.

Stages in Acquisition Management Process. The DOD acquisition management process consists of five phases which are linked by decision points known as milestones. The relationship between the milestones and the phases is shown in Figure 2.

Each milestone decision is based on information developed during the previous phase. The Defense Acquisition Board (DAB) reviews the available information and makes a recommendation to the decision authority, who decides whether or not to continue the acquisition process. Milestone reviews are designed to ensure that the program will satisfy

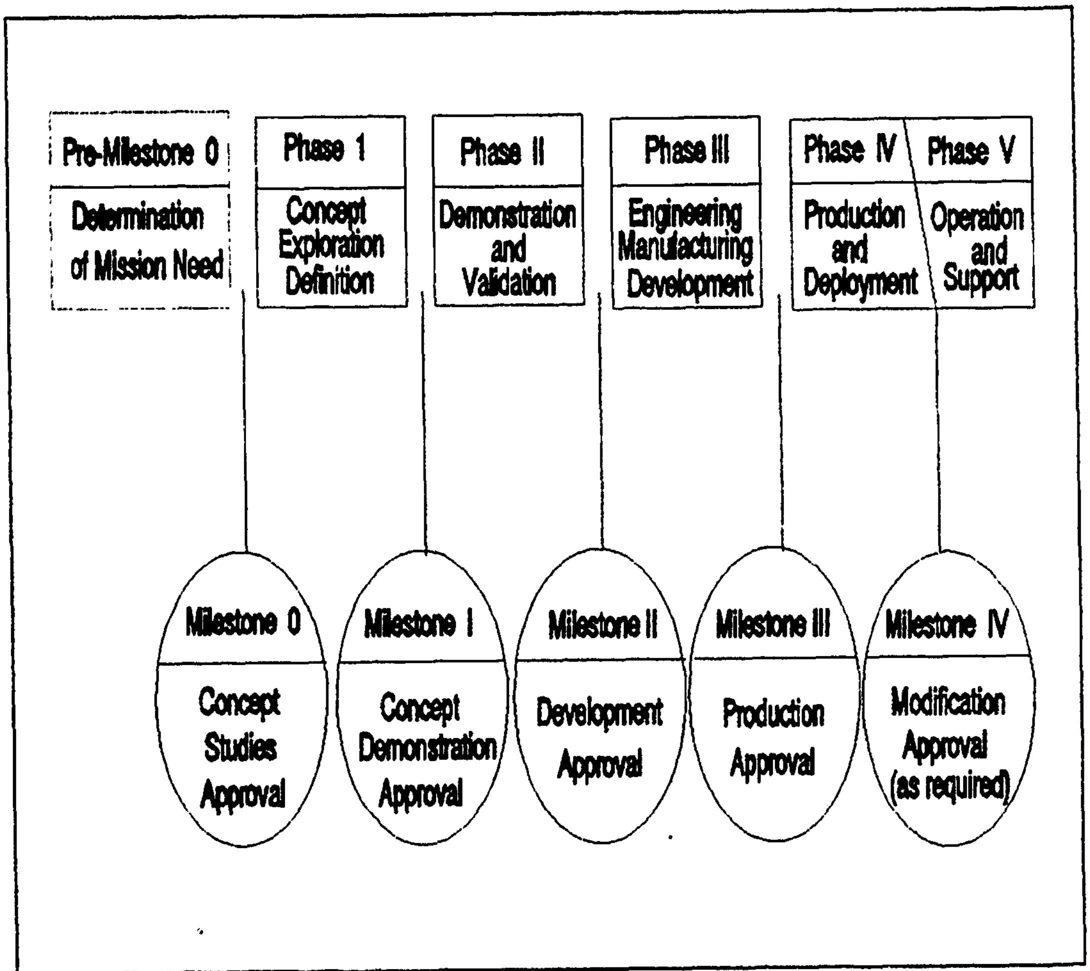

Figure 2. DOD Acquisition Process (54:Pt 2,1)

user needs and remain within approved program and financial constraints.

<u>Milestone 0--Concept Studies Approval</u>. At Milestone 0 the decision authority must decide if a MNS warrants the initiation of studies to identify alternative courses of action, and, if so, what range of concepts should be examined (54:Pt 3,6).

Phase 0--Concept Exploration and Definition. If concept studies are approved at Milestone 0, Phase 0 explores various material alternatives for satisfying the documented mission need. During this phase, the most promising system concepts are identified, and an acquisition strategy, including initial cost, schedule and performance objectives, is developed (54:Pt 3,8).

Milestone I--Concept Demonstration Approval. DODI 5000.2 notes that the objectives of Milestone I are to determine if the results of the previous phase justify the establishment of a new acquisition program, and, if so, to develop initial "baseline" program cost, schedule and performance objectives (54:Pt 3,12).

Phase I--Demonstration and Validation. During this phase, the critical design characteristics and expected capabilities of the proposed system(s) are better defined, and the contractor(s) seek to demonstrate that the technologies and processes critical to the most promising concept(s) are understood and capable of being inserted into the system design(s) (54:Pt 3,14).

Milestone II--Development Approval. At this decision point an assessment is made as to whether the results of Phase I warrant continuation of the program. If development approval is given, a baseline containing refined cost, schedule and performance targets for the program is also established (54:Pt 3,16).

Phase II--Engineering and Manufacturing Development. The objective of this phase is to "Translate the most promising design approach developed in Phase I...into a stable, producible and cost effective system design" (54:Pt 3,18). In order to do this the manufacturing and production processes must be validated, and the capabilities of the system demonstrated through extensive testing (54:Pt 3,21).

Milestone III--Production Approval. Once again, at Milestone III, a decision must be made about the future of the program based on the demonstrated results of the previous phase. If the "go-ahead" for production is given, further refinement of the cost, schedule and performance objectives is also undertaken (54:Pt 3,23).

Phase III--Production and Deployment. The objectives of Phase III are to "Establish a stable, efficient production and support base", and "achieve an operational capability that satisfies the mission need" (54:Pt 3,27). Follow-on verification testing is also included in this phase to ensure the quality of finished systems.

Milestone IV--Major Modification Approval. This Milestone is scheduled as required during Phase III, typically 10 to 15 years into the deployment of the weapon system. It is intended to ensure that "all reasonable alternatives are thoroughly examined prior to committing to a major modification or upgrade program..." (54:Pt 3,28).

Phase IV - Operations and Support. During Phase IV an assessment is made of the fielded system's continued ability to satisfy the identified mission need, and any shortcomings are identified (54.2:Pt 3,30).

Air Force LCC Structure

Long believes that the Air Force's LCC structure should be addressed from two perspectives - directives and organizations (120:19). He notes that the directives "establish the requirement and authority for LCC functions and the organizations administer and carry out those directives" (120:19).

The Directives. DODD 5000.1 requires, inter alia, that program managers (PMs) establish and present LCC goals and estimates to the Defense Acquisition Board (DAB). The DAB is the DOD's "peak council" for system acquisition and provides advice and assistance to the Secretary of Defense (SecDef) regarding acquisition decisions. DODD 5000.4 provides a permanent charter for the Office of the Secretary of Defense (OSD) Cost Analysis Improvement Group (CAIG) and establishes this group as an advisory body to the DAB on matters relating to cost. As such, the CAIG is the final evaluator of cost estimates submitted to the DAB and, thereby, establishes submission standards.

Within the Air Force, Air Force Regulation (AFR) 800-11 (Life Cycle Cost Management Program) states policies,

explains procedures and assigns responsibilities for implementing LCC management concepts. Supplement 1 to AFR 800-11 further defines the roles of AFSC and AFLC in LCC.

The Organizations. As Long notes, the CAIG "establishes criteria, standards, and procedures concerning the preparation and presentation of cost estimates to the DSARC [now DAB], and, in turn, the Secretary of Defense" (120:20). Accordingly, it is the ultimate authority on LCC analysis for the entire DOD (120:20).

Within the Air Force, Headquarters, USAF, Deputy Chief of Staff for Logistics and Engineering, Directorate of Maintenance and Supply (HQ USAF/LEYE) is the office of primary responsibility (OPR) for LCC management, and the Deputy Assistant Secretary of the Air Force (Cost and Economics), Directorate of Cost Analysis (SAF/FMC) is OPR for the analysis aspects of LCC. Here begins what Long calls a "dual line of functionalism", management and analysis, that permeates the USAF LCC functional structure (120:21). Long states that "the unifying element of the dual line of functionalism is the cost estimate itself" (120:21). Analysis is required to produce the cost estimate and management uses the estimate for decision making purposes.

At the command level, AFSC has designated Headquarters, AFSC, Deputy for Acquisition Logistics, Directorate of Program Readiness and Evaluation (HQ AFSC/ALPA) as OPR for LCC management. Similarly, Headquarters, AFSC, Deputy Chief

of Staff, Comptroller, Directorate of Cost Analysis (HQ AFSC/FMC) is responsible for LCC analysis. The same general pattern of organization is evident in AFLC where Headquarters, AFLC, Deputy Chief of Staff, Acquisition Logistics, Directorate of Acquisition and Operational Requirements (HQ AFLC/XRO) is OPR for LCC management, and Headquarters, AFLC, Deputy Chief of Staff, Comptroller, Directorate of Cost Analysis (HQ AFLC/FMC) is responsible for LCC analysis.

These two lines of functionalism finally merge at the product division level. On the AFSC side, Aeronautical Systems Division (ASD) Deputy for Acquisition Logistics, Directorate of Logistics Concepts and Analysis (ASD/ALT) is the focal point for LCC management and analysis. For Logistics Command, the Acquisition Logistics Division (ALD) Deputy for Integrated Logistics, Directorate of Software and Analysis (ALD/LSS) is the focal point for both the management and analysis functions.

Long notes that within the ASD program offices, responsibility for LCC implementation rests with the PM. This responsibility, he adds, is usually delegated to one of several offices. In some programs, it resides in the logistics area under the control of the Deputy Program Manager for Logistics (DPML); in others situations it may be handled by program control or passed onto a staff accounting

organization (120:23). The relationship of the various organizations concerned with LCC is illustrated in Figure 3.

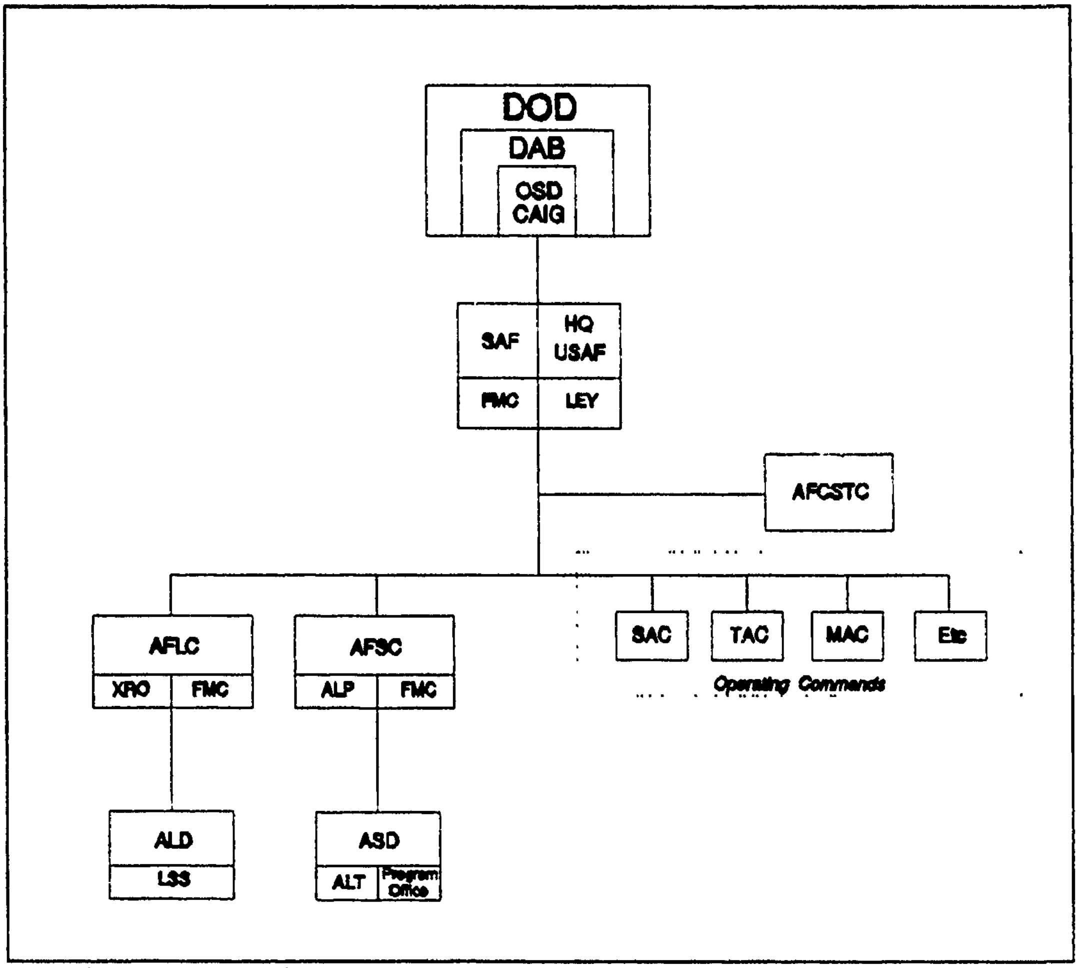

Figure 3. The USAF LCC Organization (Adapted from (120:24))

The Air Force Cost Center (AFCSTC) is also shown in the diagram. The AFCSTC reports directly to HQ USAF and SAF/FMC and was established in the late 1980s to provide cost analysis support to all levels of the Air Force. In this role, it advises the CAIG on the reasonableness and validity

of weapon system cost estimates, developes cost factors for AFR 173-13, and manages the Air Force VAMOSC system, in addition to acting as a reference point for cost analysts seeking information on various LCC models (38). While these organizations exemplify the multi-functional, multi-disciplined nature of LCC, Long believes that they also "contribute to some confusion and lack of consistent emphasis on LCC within and among various acquisition programs" (120: 23).

LCC Applications

Figure 4 summarizes the six principal applications of LCC as identified by Seldon. These uses are (141:11):

> 1. Long-range planning and budgeting. At the most basic level, LCC is a method of stimulating orderly planning. An LCC estimate reveals possible alternatives and provides a quantitative discipline for evaluating them. The need to derive money values for an LCC estimate forces management to clarify a maintenance concept or a program operation. Successive estimates provide progressively more details for planning purposes and a quantitative basis for the total budget. (141:11)

2. Comparison of competing programs. LCC analysis makes it possible to compare the costs of a number of alternative ways of meeting an operational requirement (141:11).

3. Comparison of logistics concepts. LCC allows a cost comparison of various approaches to the logistics support of a weapons system, eg., two level versus three level versus contractor maintenance. Seldon suggests that

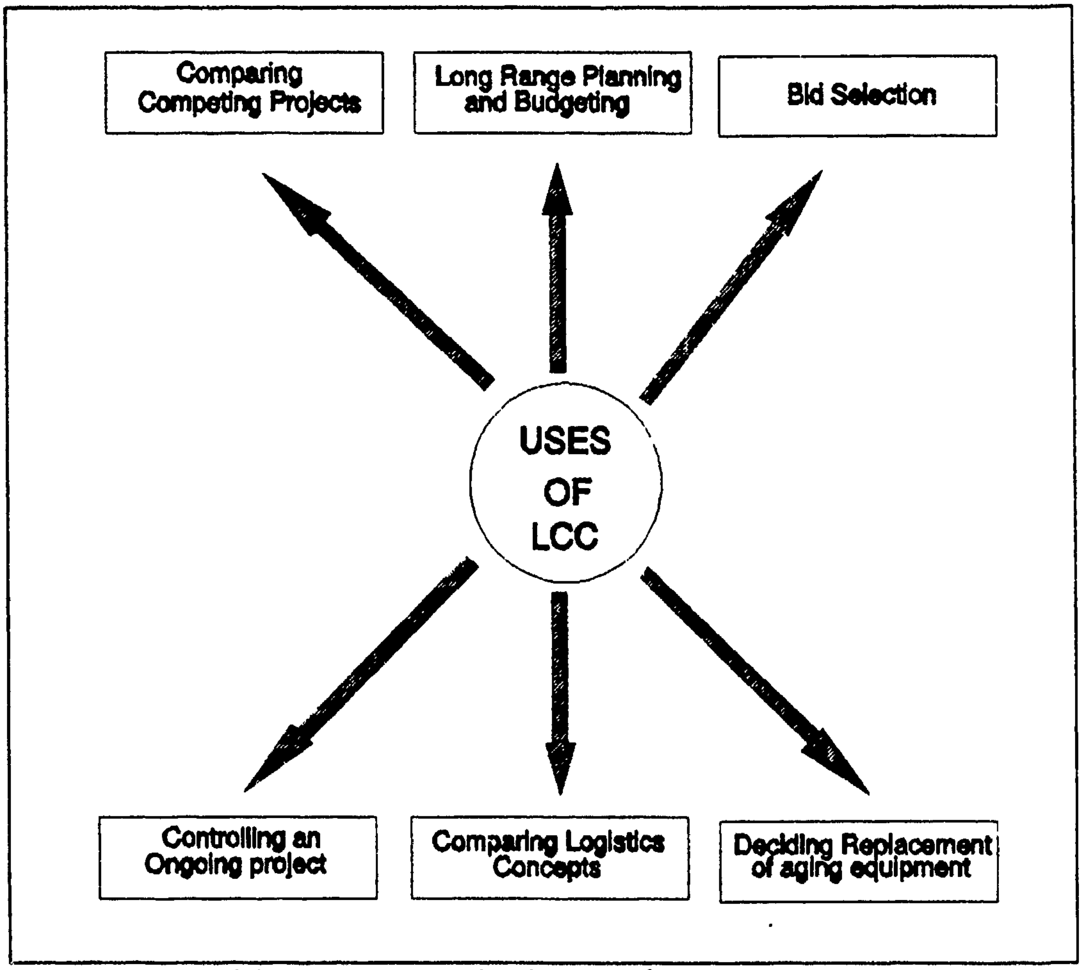

Figure 4. Main Uses of LCC (57:31)

this cost comparison is one way of overcoming the parochial views or operational bias of one section of the organization (141:11).

> 4. Decisions about the modification/upgrade or replacement of aging equipment. Often, intuitive judgements are not borne out by a quantitative analysis. Many operational personnel are swayed either by their attachment to a familiar piece of equipment or by their fascination with the exotic technology of new equipment. A cost analysis helps to separate emotion and facts. (141:11)
>
> 5. Control over an ongoing program. As a program progresses and various decisions must be made that

> involve more than one phase of the life cycle, LCC should be used as a decision criterion. Therefore the periodic evaluation of the total LCC of the program provides management with a picture of how well these decisions are being made. (141:11-12)

6. Selection among competing contractors. Seldon notes that "the most frequent use of LCC has been as a criterion for the selection of a contractor to develop and produce military equipment" (141:12).

Model Identification

The literature search also revealed that there are a huge number of LCC models currently being used within the USAF, and new models are being developed and old ones adapted almost on a daily basis to meet the needs of specific projects. In 1990, for instance, McClendon estimated that these may be in the vicinity of 3000 LCC models in existence (21:34).

Furthermore, different LCC models based on different estimating methodologies tend to be used during different phases of the weapon system acquisition cycle. May indicates that models that employ cost estimating relationships (CERs) are particularly useful during the early phases of system development, when only the "gross physical characteristics" of the aircraft may be known and a large number of alternatives may still be under consideration (124:Ch 3,5-6). However, as the design starts to stabilize and more information becomes available, May recommends that analysts

transition to models based on analogous and engineering techniques, as shown in Figure 5 (124:Ch 3,6).

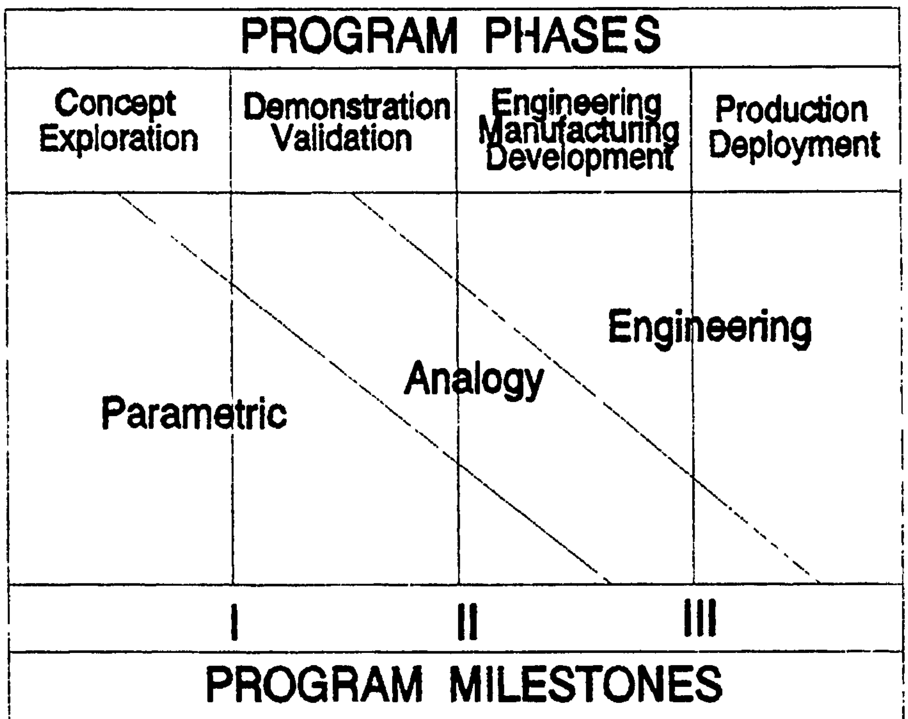

Figure 5. Transition in Use of Estimating Techniques (120:40)

With regard to identifying and locating particular LCC models (in order to make a preliminary assessment of their potential for review), the Air Force Cost Center (AFCSTC) proved a useful source of information. Through the AFCSTC, the author was able to gain access to the Cost Analysis Resource Reference System (CARRS) which provided him with a

partial list of the LCC models currently being used within the USAF and their associated OPRs. Also, the Logistics Support Analysis (LSA) Techniques Guide published by the US Army Materiel Command proved a particularly valuable source of information on LCC models being used within the DOD (94). Finally, the author was able to gain access to a substantial amount of general model information by requesting a customized search on LCC models catalogued by the Defense Logistics Studies Information Exchange (DLSIE).

III. Operating and Support Cost Models

Chapter Overview

This chapter reviews three models that concentrate on the O&S portion of a weapon system's life cycle. They are the AFLC Logistics Support Cost (LSC) model, the Life Cycle Cost H (LCCH) model, and a computerized version of the Core Orientated Resource Estimating (CORE) model called ZCORE. Using the LCC model classification scheme detailed in chapter two, both the LSC and LCCH models could be described as typical accounting models. Similarly, ZCORE is a classic example of a cost factor model. Owing to their emphasis on O&S costs, the three models could more appropriately be described as life support cost models rather than total LCC models.

The LSC Model

Background of the Model

The AFLC LSC model, Version 2.2, is part of a family of related models which have been developed and used by cost analysts and logisticians at HQ AFLC and the Aeronautical Systems Division (ASD), AFSC. The earliest version of the LSC, which ran on a mainframe computer, was develcped by AFLC/MMOAA in the early 1970s (113).

The LSC model was used early on by several program offices during source selections to estimate the difference

in logistic support costs between contractor design alternatives, and to perform tradeoff studies. For example, it was employed to compute a support resource estimate that was used as a primary source selection criterion in selecting the B-1 electronic countermeasures (ECM) package. It was also used to compare alternative avionics packages for the B-1, and was later employed by the B-1 aircraft contractor to compute the effect of engineering change proposals (ECPs) on estimated LCCs (24).

Later, a modified version of the model was used by the Air Force Acquisition Logistics Center (now Acquisition Logistics Division (ALD)) during source selection of the Air Combat Fighter (F-16). A copy of the model was passed to all competing contractors for them to develop a target logistic support cost (TLSC) for their proposals. The selected contractor (General Dynamics) was later evaluated against this target, when field data became available (23). This version of the model was upgraded in 1979.

After 1979, ALD continued to maintain Version 1.1 for use in ASD system program offices (SPOs), and it remained virtually unchanged until 1986, when different SPO users began to let contracts to revise the ALD LSC model to meet their specific needs (1).

In 1981, analysts with HQ AFLC/ACC reduced the number of cost elements in Version 1.0 of the AFLC maintained LSC model and extensively revised its code. The revision incorporated

equation and input/output format changes developed by AFLC analysts so the model would reflect the different requirements of estimates made for a range of weapon systems during source selections and ICAs. Version 1.1 computed the costs of pipeline and condemnation spares, depot maintenance, and second destination transportation of LRUs and SRUs from bases to depots. Equations and throughputs for other ALD LSC cost elements, such as item inventory management and off-equipment maintenance, were dropped (113).

AFLC analysts have continuously updated the LSC with an extensive revision of Version 1.1 performed in 1984. Changes included:

1. the calculation of factors for the CORE model,
2. the addition of SRU factors, and
3. the addition of support and training equipment spares factors. (1:Sec II,2)

LSC Version 1.5 was rehosted on the Z-100 PC using FORTRAN IV in 1985 and contained additional output options and revised SRU and out-of-production (OOP) factors. Version 2.0 was written in GW-BASIC in 1987 for use on the Z-150 and Z-248 PCs and incorporated a wide range of revisions and added capabilities (113). The latest version of the LSC model was released in October 1990 following a validation study of the model conducted by Management Consulting and Research Inc (MCR).

Purpose of the Model

The LSC is a generic accounting model which can be applied to a range of weapon systems, whether airborne or otherwise, to forecast AFLC related O&S costs such as initial and replenishment spares, depot maintenance and second destination transport (TDT). Owing to the fact that the model focuses on only a subset of O&S costs, it cannot be regarded as a complete LCC model. More specifically, the model's equations estimate the annual costs for condemnation spares and spares used to fill the supply pipeline between bases and depots. In relation to maintenance costs, the model considers only the depot portion of total system repair costs, excluding organizational (flight-line) and intermediate (shop) level maintenance expenses. TDT involves the movement of reparable items from bases to maintenance depots and return. The LSC model calculates these costs for each individual reparable item (LRU or SRU) in the model's input file over the entire deployment life cycle of the weapon system (1:Sec III,2).

General Characteristics of Model

The LSC model has three main input files:

1. system file,
2. hardware file, and
3. cost file.

These files are mandatory and must be supplied by the user to

run the model properly. The system file contains overall information on the weapon system being costed, such as the logistics scenario and operations activity, necessary in order to run the LSC model (93:Sec 3,12). The hardware file contains a description of each hardware item in the system identified in a hierarchical fashion under the Work Unit Code (WUC) of the sub-system (93:Sec 3,12). For example, an aircraft contains many sub-systems (identified by the first two digits of the WUC) such as the landing gear, engine and radar. The radar, in turn, consists of LRUs (e.g, antennae, transmitter) which themselves contain SRUs (e.g, circuit cards) (1:Sec III,2). The cost file is used to assign unit costs to LRUs (or SRUs) for computing spares costs. Every LRU in the hardware file has a corresponding entry in the cost file (93:Sec 3,18).

Model Assumptions

The current version of the LSC model (Version 2.2) makes the following assumptions (93:Sec 2,1):

1. Safety stock quantities and pipeline spares quantities are based on the peak level of monthly program activity.

2. Only one depot repair facility is allowed, although there can be any number of base level repair locations.

3. Spares for support equipment are computed as a percentage of support equipment acquisition cost and are not

directly related to program activity. The acquisition cost of support equipment is input by the user, i.e., it is not a quantity derived by the model.

4. Certain cost elements which contribute to life cycle logistic support cost are excluded from the model because there is no analytical basis for estimating their effect, e.g, Class IV modification costs.

5. All items are repaired during the stated base or depot repair cycle time, regardless of the quantity submitted for maintenance, i.e, no maintenance backlogs occur.

6. The computation of spares is completed on an LRU by LRU (or SRU by SRU) basis. That is, each LRU or SRU is treated independently. There is no marginal analysis or tradeoff between LRUs and SRUs. (93:Sec 2,1)

7. The scenario for the model is monthly aircraft operations at an air base (1:Sec III,3). Accordingly, equation variables use terminology appropriate to airborne weapon systems, e.g, flying hours, item quantity per aircraft (QPA). However, the model may be applied to a range of weapon systems or other equipment (1:Sec III,3).

Uses of the Model

The user's manual for Version 2.2 of the LSC model identifies five potential uses for the model (93:Sec 1,1). These are:

1. Cost estimates performed on new weapon system

procurements or proposed modifications to existing systems.

2. Design tradeoffs and analysis of the influence of design changes on LCC.

3. Comparison of the LCC of proposed contractor design configurations during the source selection process.

4. "Evaluation of engineering change proposals (ECPs) and design alternatives by Program office personnel" (93:Sec 1,1).

5. "Estimating provisioning spares requirements" (93:Sec 1,1).

In practice, AFLC/FMC, the main users of the model, use the model for:

1. source selections,

2. preparing ICAs for the CAIG,

3. conducting cost and operational effectiveness analyses (COEAs),

4. performing general weapon system LCC analyses, and

5. providing AFLC related inputs for running the Cost Orientated Resource Estimating (CORE) model, which is used to estimate annual aircraft squadron O&S costs in accordance with AFR 173-13 (113).

Model Data Sources

The input data requirements for the LSC model are extensive and, usually, AFLC cost analysts must undertake a time consuming search to identify relevant data. Data is

obtained from a variety of sources including production contractors, SPOs, system program managers (SPMs) and ALD integrated logistic areas. Little information is extracted from automated databases unless an analogy estimate is being prepared for a new weapon system prior to Milestone II in the acquisition process. For example, the advanced tactical fighter (ATF) Milestone II ICA used F-16 data in the LSC model to develop an O&S cost estimate. However, generally the LSC model is not used before Milestone III (131). In the above case, depot maintenance costs for the F-16 were extracted from the Weapon System Cost Retrieval System (WSCRS). VAMOSC is generally not used as a data source, except to obtain TDT costs (for which it is the only source) because of concerns about the validity and accuracy of the data residing in the system.

Classified data sources are rarely used in estimates prepared using the LSC model (the ATF is an exception). The data required by the LSC model is not unique to the model and is available to be used elsewhere. The model uses base year constant dollars in its estimates. If inflationary influences need to be accommodated in estimates using the model they must be applied to outputs outside the model. The affect of technological change is not explicitly addressed by the model.

A new cost database is developed from information extracted from data sources for each LSC cost estimate. Each

WUC forms a separate record in the database under which LRUs/SRUs and associated reliability and cost information is detailed. AFLC/FMC cost analysts attempt to obtain information from the best available sources for input into the model, but the model cannot be calibrated in any way to test the validity of the data gathered. Sanity checks are performed on several data items to ensure the reasonableness of input parameters, however, in the end, the credibility of model output must be judged by the cost analyst.

Shortcomings of the Model

The shortcomings of the LSC model and most other LCC models can be divided into three broad categories. These are:

1. unrealistic assumptions,
2. errors and omissions, and
3. model limitations.

Each of there areas of weakness will be examined in turn for the LSC model.

Unrealistic Assumptions. Of the seven model assumptions presented earlier in this chapter, two stand out as being particularly unrealistic and have the potential to undermine the credibility of any estimate prepared using the LSC model. The first is the assumption that all unserviceable items are repaired within the designated base or depot repair cycle time, i.e., no maintenance backlogs occur. This is a gross

oversimplification of reality. In practice, the speed with which a repair job moves through a depot depends on the priority of the work, the workload of the particular repair station involved, whether parts are immediately available to complete the repair, and numerous other factors. In other words, queuing and backlogs are an inherent part of depot maintenance and should be accommodated in repair cycle calculations. The second dubious assumption relates to the calculation of support equipment spares. Support equipment spares are currently computed as a factor of support equipment acquisition costs and are not directly related to program activity. The model works on the basis of a "bed-down" base in calculating support equipment spares requirements and makes no allowance for the increased usage of parts as a result of deployment activity. Also, support equipment factors are "hard wired" into the model preventing any activity related adjustment. The user's manual for Version 2.2 of the model does suggest, however, that if sufficient support equipment LRU and SRU data is available the information should be run through the main part of the model rather than using support equipment factors (93:Sec 3, 20). Version 2.2a of the LSC model, which will be released later in 1991, will allow the user to access the support equipment factors file to update or modify the support equipment factors to account for weapon system activity level variations.

Errors and Omissions. The LSC model contains several errors and omissions, which are detailed below.

SRU Factors. The area of the model requiring the most immediate attention is the SRU factors (SRUFACs) file. The LSC model uses SRUFACs in calculating pipeline spares to adjust the estimate generated for an LRU when it contains SRUs, but not enough information is available on the SRUs to run them in the model along with the LRU (93:Sec 3,22). For example, a factor of 2.0 would indicate that SRUs account for one-half of the pipeline spares costs for a specific two digit WUC. Emphasis is placed on pipeline spares in the LSC model because of the need to budget for them within the acquisition phase of a program.

The 1990 MCR validation of the LSC model indicates that:

> The first set of SRUFACs were added to the model during the F-16 ICA (1979). Additional factors were added during the HH-60A and Next Generation Trainer source selections and ICAs (1981-2), and the B-1 ICA (1982). Many of the factors were developed using contractor data for specific weapon systems or avionics suites. Some of these have been revised since then, but no studies have been performed to validate them. SRUFACs have not been developed for about half the two-digit WUCs and default values of 1.0 are used for LRU/SRUs under these WUCs. (1:Sec VI,2)

As part their validation study of the LSC model, MCR performed an analysis of the LSC SRUFAC methodology. This included the following (1:Sec VI,3):

1. comparison of standard LSC SRUFACs with SRUFAC ratios computed using actual LRU data from three F-16 subsystems, and

2. examination of the sensitivity of SRUFACs to changes in input variables and different combinations of these changes.

The comparison was performed to determine whether the SRUFACs in the LSC model would give the same result, when applied to an LRU, as the model calculates when detailed SRU information is available on the same LRU. The sensitivity tests aimed to reveal whether different input scenarios change the SRUFAC values (1:Sec VI,4). MCR found that not only might the current default SRUFACs not be realistic, (their conclusion was qualified because of the small selection of WUC types in the sample of F-16 data) but a simple factor methodology may not be the best way to provide the needed capability. Additionally, the sensitivity test revealed that SRU ratios do vary for different LRU/system input combinations and that this sensitivity can be roughly predicted, using regression analysis, based on LRU and SRU composite costs and, possibly, MTBD characteristics (1:Sec VI,15). Based on the findings, MCR recommended that the SRUFAC methodology currently used in the LSC model should be extensively revised to make the factors sensitive to LRU and system input variable values (such as basing strategy and operation rates). MCR also recommended that the revised SRU methodology be extended to develop factors which could be used in estimating the SRU contribution to other cost

elements, such as condemnation spares, repair labor and transportation (1:Sec IV,12; 1:Sec VI,17).

In light of the consultant's recommendations, HQ AFLC/FMC has initiated projects at several ALCs in an attempt to develop more accurate SRUFACs for different weapon systems using the methodology developed by MCR (133).

Other Factor Problems. The LSC uses three other types of factors to adjust the basic spares calculations performed by the model because of unusual demand phenomena. These factors are the engineering change order (ECO) factor, the out-of-production (OOP) factor and churn factor.

ECO Factors. The ECO factor is applied by year to cumulative pipeline spares cost during the phase-in period of the weapon system being modelled to estimate the cost of ECOs. The ECO factors are used to estimate the costs that are incurred during production years when changes to the physical, performance, maintenance or logistics characteristics of a system necessitate changes to components and, therefore, spares requirements. The model assumes that additional spares have to be bought to support the spares already in the system as they are progressively withdrawn for modification (93:Sec 3,6). The MCR study noted that the LSC model applies ECO factors by year to only the incremental portion of that year's total pipeline spares cost when in fact the factors should be applied against the annual cumulative total spares cost. This, MCR suggests, is

necessary to account for "the cost of performing configuration changes or retrofits to many or all of the spares already produced" (1:Sec V,5). Therefore, the LSC model is currently underestimating ECO spares costs when ECOs occur during the latter years of production when most of the production run will require modification (1:Sec V,6).

<u>OOP Factors</u>. OOP factors account for the increase in the unit cost of a reparable item when a closed production line must be restarted to continue supply (93:Sec 3, 23). The MCR report notes that when spares are purchases intermittently in small lots, the OOP effect can greatly increase their cost (1:Sec V,7). The LSC user's manual recommends that OOP factors be developed for each estimate based on the latest research available, and mentions a study done by Mr Stephen Klipfel in 1986 (93:Sec 3,23). However, very few sources exist for OOPs, whether general in nature or tailored by LRU or WUC. MCR indicates that the general OOP effect is known but very little research has been performed on it. Consequently, they conclude that the accuracy of LSC estimates is questionable, "not because of the use of OOP, but because of its value(s)", and recommend that a reliable OOP methodology be developed by the Air Force (1:Sec V,7).

<u>Churn Factor</u>. Churn factors, the LSC model user's manual notes, are values which adjust condemnation spares costs to account for greater than anticipated demand during system phase-in (93:Sec 3,22). The MCR report notes

that the following factors drive the churning of condemnation spares:

1. new items entering the inventory,

2. fluctuations in demand rates,and

3. configuration changes in existing spares items due to modifications. (1:Sec V,8)

The MCR report goes on to add that while it is logical to include a churn factor in the LSC model, it is difficult to find "reliable calculations of the size of the factor or methodologies which allow the analyst to tailor churn for different sets of LRU/SRUs" (1:Sec V,8). The current churn value used in the model was derived by AFCSTC analysts in 1988 using seven years of historical data on nine different aircraft types (1:Sec V,8). The MCR report also highlights a HQ AFLC Comptroller study indicating a general churn factor range of 1.5 to 2.5 (1:Sec V,8). The weakness of the model is that the churn factor cannot be varied using sensitivity analysis to gauge the magnitude of its affect on replenishment spares costs.

<u>Operational Availability Calculations</u>. Availability is the basic measure of the operational readiness of a weapon system (1:Sec VII,1). To give a true indication of the likely status of a weapon system, an operational availability measure must take into account any action that might affect the maintenance/repair time of the system. In addition to reflecting the time involved in corrective maintenance, as

well as delays in performing such actions, it should take into account preventive maintenance time since the system is also not available for operation during such periods although no particular problems have been detected. However, the operational availability equation used by the LSC model does not include a preventive maintenance term, meaning that weapon system availability is overestimated (1:Sec XI,3).

Consumables. The LSC model does not estimate the cost of initial or replenishment consumables. Consumables, which are stock funded, are usually estimated as a percentage of reparable spares investment costs. The ability to estimate consumable (as opposed to reparable) stock fund spares would be a useful addition to the LSC model, since its incorporation would remind the analyst to include this often overlooked cost element (1:Sec IX,17). The cost can be easily calculated using the spares information produced by the model.

Model Limitations. This section examines some of the limitations of the LSC model identified in the recent MCR validation study, as well as reviewing some criticisms of the model put forward by earlier reviewers. In the latter case, an assessment is made as to whether the highlighted weaknesses have been overcome in subsequent versions of the model as it has evolved.

Design Tradeoff Limitations. One of the fundamental criticisms of accounting type models, such as the

LSC, made by the JCWG in a review of existing LCC models in 1976 was that such models were of little use in design tradeoff studies. The user's manual for Version 2.2 indicates that one of the primary uses of the LSC model is in "Determining design trade-offs and design impacts on life cycle costs" (93:Sec 1,1). The JCWG was critical of accounting models for not being able to be used early in the conceptual planning and design phases of a new weapon system, when the majority of subsequent O&S costs are determined. This, they suggested, was because the models computed O&S costs as a function of R&M characteristics such as MTBF rather than directly relating O&S costs to performance and design parameters such as material types and weapon system speed.

This criticism still applies to LSC model, although it is not as relevant as it was in the mid 1970s because of the requirement to set system reliability targets earlier in the acquisition process. However, the LSC model still is, essentially, a model driven by reliability parameters. Additionally, as mentioned previously, the depth of information required to run the LSC model usually precludes it from being used before Milestone III in the acquisition of a new system. However, work is being done in this area in an attempt to bring the LSC into play in the earlier and more relevant phases of acquisition. A recent study by Capt Anne Dement of ALD/LSS demonstrated the feasibility of applying

demand based initial spares cost estimating in early acquisition phases using the LSC model (36). Using comparative spares information from the F-16, she was able to arrive at a Milestone II estimate of initial spares costs for the ATF. The usefulness of this estimate, compared to traditional parametric techniques, remains to be seen, however, it is a step in the right direction.

Use of Availability Measures. The LSC model was also reviewed in a 1978 study of USAF aircraft system models conducted by the Rand Corporation (122). The major criticism levelled at the LSC model in that study was the fact that the model provided no link between spares costs and the overall effectiveness of the supply system or aircraft availability (122:23). The version of the LSC model reviewed in that study was prepared in 1976 and contained no weapon system availability measures. Version 2.2 of the model contains three availability measures. The most useful of these availability indices is the calculated operational availability (COA) equation mentioned previously. COA uses a combination of mean time between removal (MTBR) and mean down time (MDT) at the system and sub-system levels to approximate mean time between maintenance (MTBM) and thus derive a measure of weapon system availability. However, as mentioned previously, preventative maintenance is not included in the availability calculation, undermining its value. Furthermore, the LSC model does not provide the user with the capability

to specify a weapon system operational availability target and work backwards to adjust target fill levels and failure rates accordingly (1:Sec XI,3). This deficiency limits the usefulness of the measure. The MCR report notes that:

> Spares optimization (adjusting the spares level of each item to achieve a given availability at the lowest combined spares cost)...is infeasible within the level of complexity envisioned for the LSC model. (1:Sec VII,14)

MCR attributes this infeasibility to the significant data requirements and computational intensity of such a change (1:Sec VII,14). However, MCR suggests that it would be feasible to add some dynamic "what if" capabilities to the model, without adjusting the present operational availability equation, to allow the user to view the effects of various reliability and fill rate changes on system availability (1:Sec VII,24).

Maintenance Level Comparisons. The current version of the LSC model allows the user to model two or three-level maintenance concepts (93:Sec 2,6). The capability to model other maintenance scenarios would a useful addition to the model. MCR notes that AFLC analysts connected with the KC-135R ICA in 1982 modified the LSC's code to accommodate the regional intermediate repair of engines (1:Sec X,5). MCR suggests that this capability should, once again, be added to the model, "both to make these maintenance concepts available to all users and to avoid the need for analysts to make needed, but unauthorized, changes to the code" (1:Sec X,5).

Commonality. The LSC model does not have the ability to handle commonality, i.e., sparing and repair requirements of an item used simultaneously by a number of weapon systems (1:Sec X,5). The model can be used in estimates where there are items common to different weapon systems, by performing multiple runs, but the results of these separate efforts cannot simply be added together to estimate economies that might be involved in weapon systems sharing the same logistics networks (1:Sec X,6). The Standard Evaluation Program (STEP-3) is the only model currently available with the capability to evaluate the LCC impact of item commonality (31).

Model Input/Output. The LSC model does not use spreadsheet or database input/output interfaces to facilitate the entry and manipulation of data. The current method of building an input file and making edits in ASCII is cumbersome and time consuming and doesn't allow the user to easily set-up and change large files. Data entry would be quicker and easier to perform using standard spreadsheet or database input file formats.

Additionally, output formats cannot be manipulated by the user to perform additional analyses. Frequently, output data has to be manually transferred to a spreadsheet to apply inflation factors for then-year estimates. An improvement incorporated in the latest version of the model is the ability to send formatted output to an ASCII file, thus

relieving analysts of the burden of manually transfering data for further manipulation (93:Sec 1,3).

<u>Support Equipment Factors</u>. As mentioned previously, the LSC model has weaknesses in its factors file. For support equipment this means that the factor approach should only be used for simple electro-mechanical equipment or items that have a known lifetime. Factor estimates are not appropriate for complex pieces of equipment such as simulators (1:Sec IV,18). The user's manual recommends that if sufficient LRU/SRU information is available on support equipment components then they should be run through the main part of the LSC model (93:Sec 3,20).

<u>Base Level Maintenance Costs</u>. Base level maintenance costs, other than spares, are not calculated by the LSC model (93:Sec 2,1).

<u>Data Intensity of Model</u>. Despite the fact that the LSC model omits a number of O&S cost elements, it is still a very data intensive model and requires that information be gathered from a number of different sources. HQ AFLC/FMC estimates that a cost analysis using the model can take an analyst anywhere between three and 24 months, depending upon the size of the project, the level of detail required in the estimate and the availability of cost information (113).

<u>Depot Maintenance Cost Omissions</u>. One of the three main O&S cost elements considered by the LSC model is depot maintenance. However, the cost estimated for this element is

not all-inclusive. The LSC model only considers depot maintenance costs which are incurred as a result of component failures at the base level. Falling outside this category of costs are the following depot maintenance activities (113):

1. programmed depot maintenance (scheduled overhaul),
2. analytical condition inspections, and
3. Class IV modifications.

The cost of these repair activities must be calculated outside the model using industrial engineering estimating techniques (113).

Base Safety Stock. The LSC model's base pipeline spares equation uses a factor (FMOD) to set the size of the safety stock of reparables needed at the base level to satisfy an average ready rate (probability of satisfying demands made with stock off the shelf) during resupply (1:Sec III,4). However, only one FMOD factor can be used in the model, and this factor sets the stockage levels for each LRU/SRU item in the input file. MCR notes that although the average target ready fill rate is 92 percent, engine reparables "commonly have a ready rate from 85 percent to 90 percent, while many avionics components have rates above that" (1:Sec III,21). In other words, flexibility is required in the setting of ready rates and the LSC model should allow the user to set an FMOD for every item in the input file, or at least each two-digit WUC, while maintaining the capability to use a default value (1:Sec III,21).

Depot Repair Cycle Time. The depot repair cycle time (DRCT) is currently underestimated by the LSC model owing to the fact that time spent on condition inspection of items which are subsequently condemned because they are uneconomical to repair is not included in the DRCT equation (1:Sec III,33). Although condemned items are not repaired, a waiting and service time is still associated with them and time spent on these spares increases the repair time of other unserviceable items. Furthermore, additional time should be added to the repair cycle equation to account for the time lost when part stockouts occur (AWP). However, the equation cannot be modified because AFLCR 57-4 states that AWP should not ordinarily be included in DRCT.

Model Maintenance and Use Costs

The LSC model is a microcomputer based model that runs on standard USAF Z-248 terminals. The model requires that the analyst build a new database for each estimate performed. It is the gathering of information for input into the model that takes the majority of the estimator's time. HQ AFLC/FMC, the proponents and maintainers of the LSC model, estimate that the average data search can take anywhere from six to 12 man months. Typically, an analyst may spend anywhere between three and 24 months (depending upon the nature of the estimate being prepared) gathering data, inputing it into the model, analyzing the results and

preparing the cost analysis report (113). An AFLC/FMC analyst is usually a GS-12/13 or Captain/Major with an average standard composite salary in the vicinity of $5000 per month (102). Consequently, the direct manpower costs involved in preparing an LCC estimate using the LSC model range from $30000 to $120000. A costing exercise performed by AFLC/FMC several years ago estimated that it cost in the vicinity of $1,000,000 to prepare an ICA on a major project for submission to the CAIG by the time the data had been gathered, verified and input to the model, and the subsequent report had been prepared, revised and filtered through the normal chain-of-command (113).

In additional to the above mentioned direct labor costs incurred in preparing LSC estimates, AFLC/FMC has a programmer/analyst working full-time on the model to maintain and improve it, and resolve any "bugs" in the program that may be detected by analysts when preparing estimates.

Contractors are rarely used in the preparation of estimates using the LSC model, the only exception being some data research when information is not available within the Air Force system or has proven particularly difficult to track down.

<u>Benefits of Model Use</u>

<u>Decisions Made Using Model</u>. Billions of dollars worth of initial spares purchases made by AFLC are impacted

annually by use of the LSC model. For example, seven billion dollars worth of spares were estimated for the C-17, using the LSC model, out of a total LCC projection of $50 billion for the program (113). Additionally, during source selection the model's O&S cost estimate can be the deciding factor in determining which tenderer wins a contract (113).

<u>Decisionmaker Confidence in Model</u>. The LSC model has been used extensively since it was first introduced in the early 1970s. The status of the model was significantly enhanced by its successful employment in the F-16 contract and its use and acceptance increased accordingly. However, AFLC/FMC indicates that key decisionmaker confidence in the use of the model remained only fair because of concerns over the validity and accuracy of the information being fed into it.

In an attempt to allay these fears, the AFCSTC sponsored a validation study of the model that was completed by MCR in May 1990. In the study, MCR examined the logic of model equations and factors; the validity of model inputs and outputs; and the flexibility of the model. As part of the validation effort, MCR developed a sample input data base, using actual F-16 spares requirements information, ran the data inputs through the LSC model and compared the results with the output of the DO41 (AFLC Recoverable Consumption Item Requirements System) (1:Sec 1,3). DO41 is the system used by AFLC to estimate replenishment spares requirements.

However, in order to do this DO41 must first determine gross requirements for reparable items, including initial spares. DO41 cannot be used in LCC because it requires several years of actual usage data in order to generate an estimate.

Since DO41 provides the official requirements projections for the USAF, the LSC sparing equations must duplicate, as closely as possible, DO41 calculations (1:Sec III,44). MCR found that when the LSC and DO41 equations were run using the same set of inputs, the differences in estimated requirements were only due to differences in the models' respective rounding routines (1:Sec IX,15). These results should give decisionmakers renewed confidence in the output of the LSC model.

Model Sensitivity Analysis Capabilities. Prior to the most recent release of the LSC model, sensitivity analysis could only be performed on one parameter--MTBR. However, Version 2.2 of the model has seen the model's sensitivity analysis capabilities enhanced significantly. Sixteen system parameters are now able to be manipulated to gauge their effect on LCC (93:Sec 1,2). This increased trade-off capability has proven particularly useful in the conduct of COEAs.

Model Improvement and Validation

The LSC model used by AFLC has evolved considerably since it was first developed in the early 1970s. Model

equations have been updated and added in response to changes in the inventory and repair systems; multi-base and multi-year analysis capabilities have been included; SRU factors have been incorporated in the model; the user interface has been made more "user friendly", eg, help menus have been added; data input mechanisms have been simplified; and sensitivity analysis capabilities have been enhanced.

An assessment of whether these changes have resulted in "real improvements" to the model is difficult owing to the fact that the model was not formally validated before 1990. If improvement is measured in terms of the increased capability and user friendliness of the model, then one could quite reasonably conclude that the model has improved. If improvement is measured in terms of the increased use and acceptance of the model, then, once again, one could conclude that improvement has taken place. The MCR study revealed that the LSC model is, essentially, logically sound and can replicate the results of systems it is intended to mimic given reasonable inputs, eg, D041. The LSC model has also been accepted by the AFCSTC and OSD CAIG for use in preparing ICAs. Thus far, it is the only LCC model to be validated and accepted by these organizations, and, accordingly, has established itself as a "benchmark" model.

As mentioned previously, the LSC model is a data intensive estimating tool. A considerable amount of time and effort is required to gather the data needed to run the

model. This data requirement is probably the main factor restricting improvement to the model. An expansion of the model to include other relevant O&S cost categories could not be considered, realistically, until the data gathering leadtime is reduced significantly. The LSC model needs an ability to interface with other automated O&S cost databases to allow the rapid identification and transfer of relevant data. Also, the inability to test model predictions against actual data is a large problem, not only for the LSC but every other LCC model being used by the USAF. There are several reasons for this:

1. System configurations often change significantly between the time an LSC estimate is prepared and weapon system deployment. Consequently, it is extremely difficult to establish a baseline for comparison purposes.

2. When validation efforts are attempted, such as the one performed on spares by MCR, they are found to be extremely time consuming because of the different nomenclature used by various data systems and the various sources that must be queried in order to obtain relevant information. Generally, time limitations mean that smaller sample sizes must be accepted, thus restricting the ability to draw statistical inferences from the results.

3. Also, because of the time it takes to close the validation feedback loop i.e., five to 10 years after a system has become operational, organizations tend to view

validation efforts as mainly academic exercises that have little practical significance. Consequently, validation efforts are given low priority or are sub-contracted to outside consultants on an ad-hoc basis.

Owing to the above problems, program modifications to the LSC model have generally been "validated" by AFLC/FMC using a face validity or appraisal of concept approach, rather than comparing model results against actual data (113).

The LCCH Model

Background of the Model

The LCCH model was developed in 1985 by Mr John Huff of ALD/LSS. LCCH is one of a family of accounting models used by AFSC and AFLC, which includes the LSC model. In fact, the origins of the LCCH model are firmly rooted in the LSC model. A predecessor of the LCCH model, the LCC-2 model, was developed for ASD by the Analytical Science Corporation (TASC) in 1976, for use on the OMEGA project, using the LSC model as a base (103). LCC-2 sought to expand on the LSC model to provide a more complete O&S cost coverage by including cost elements such as base level maintenance, initial training, and data and item management. Subsequently, in 1979, Dynamic Research Corporation (DRC) was contracted by ASD/AEAC to revise the LCC-2 model to allow more accurate cost estimation during Standard inertial navigation system

production source selection for the A-10A (42:Sec 1,1). This version of the model, which became known as LCC-2A, permitted centralized intermediate level maintenance, computed intermediate level support equipment requirements based on demand, and allowed a change in maintenance concept from two to three-level partway through a system's life cycle, as well as offering additional output products (42:Forward). LCC-2A became LCCH when Mr John Huff modified the code to separate acquisition (pipeline) spares costs from O&S (condemnation) spares costs.

The only change to the LCCH model since then has been its rehosting on microcomputer in 1986. The original LCCH model and its predecessors had been designed to run on either the AFLC CREATE mainframe computer system or use time-sharing arrangements (104:11).

Purpose of Model

The original LCC-2 model was developed to evaluate the costs of acquiring and supporting an avionics system over its operational life. Subsequent revisions of the model have broadened its applicability and the LCCH model can now be described as a general (active system) O&S cost model. However, LCCH is only a partial LCC model because it does not include research development testing and evaluation (RDT&E) or disposal costs in its estimates. Additionally, although acquisition costs can be included in the model they are

treated as "throughput" costs and are not actually derived using model equations. The user's manual for the LCCH model indicates that it is useful for:

> comparing support concepts (e.g., two versus three level maintenance) evaluating Reliability Improvement Warranty (RIW), performing sensitivity analysis, and identifying cost driving parameters in a system acquisition program. (42:Forward)

The manual also alludes to the fact that the model should only be used for "cost comparisons", rather than "cost estimates", because its O&S cost categories are not all inclusive (42:Sec 1,1); this restriction in model usage is also stressed by the proponent of the model, ALD/LSS.

General Characteristics of Model

The program for the LCCH model is written in FORTRAN IV. The model has five main input files:

1. standard cost factors,
2. logistics factors,
3. hardware definition data,
4. support equipment data, and
5. contractor data. (42:Sec 3,17)

These files are mandatory and must be supplied by the user to run the model properly. The standard cost factors file contains standard labor, shipping and material consumption rates, detailed in AFR 173-13 (USAF Cost and Planning Factors), which are needed for model computations. The logistics factors file sets the support scenario for the

system being analyzed. Included in this file is information on the operational life of the system, the number of systems that will be deployed and the number of bases where these systems will be located, as well as system operating times and depot and base repair periods (42:Sec 3,20). The third file, the hardware definitions file consists of parameters which define and characterize the hardware configuration of the system, such as weight, number of replaceable units (NRUs) and mean time between failures (MTBF) (42:Sec 3,23). A separate data record is required for each replaceable unit (LRU or SRU) in the system (42:Sec 3,22). Support equipment parameters, such as the number of test sets and the cost per set, are included in the support equipment file (42:Sec 3,27-28). Finally, the contractor data file consists of tenderer proposal parameters, including item acquisition cost, number of new inventory items required and warranty price.

Model Assumptions

The current PC version of the LCCH model makes the following assumptions:

1. If warranty coverage is provided in a contract, depot level repair costs are assumed to be included in the warranty price, while the warranty is in effect, and, accordingly are not included in the system LCC (42:Sec 2,29).

2. Reliability growth can occur during the operation of a system.

3. System hardware acquisition costs are known (10:24).

4. The demand for spares follows a Poisson probability distribution (42:Sec 2,17).

5. The demand rate for spares is the rate at final system installation (42:Sec 2,22).

6. The quantity of spares required to support system operation is driven by system availability objectives (42:Sec 2,15).

7. Maintenance manpower costs (flight-line, base and depot) are directly related to maintenance manhours (42:Sec 2,27-29).

8. If a warranty option is exercised, the government is not responsible for the following depot level maintenance costs during the warranty period (42:Sec 2,29-35):

a. initial training of maintenance personnel,

b. technical data acquisition and management,

c. initial and recurring inventory management, and

d. depot level support equipment maintenance.

However, the model also operates on the basis that the government will absorb all the costs associated with packaging and shipping reparable items moved between the base and the contractor's depot maintenance facility (42:Sec 2,33).

Uses of the Model

The user's manual for the PC version of the LCCH model identifies six "typical" uses of the model. These are:

1. Comparative evaluation of alternative support concepts including Reliability Improvement Warranty.

2. Investigating sensitivity of life cycle cost to uncertain parameters (MTBF, Turnaround Time, Usage Rate, etc.)

3. Determination of spares quantities that must be provided at the base and depot levels to meet system availability objectives.

4. Optimum Repair Level Analyses that are optimized at the System rather than Replaceable Unit level.

5. Identification of the important cost driving parameters in the system acquisition program.

6. Estimation of manpower requirements at each repair level. (42:Sec 1,1)

Model Data Sources

Like the LSC model, the input requirements for the LCCH model are extensive. The primary source of information for input into the model is the system development contractor (103). In addition to providing information on ·quisition costs, the contractor supplies system configuration and reliability information for inclusion in the hardware definition file, and specifies the support equipment needed. Standard cost factor information is obtained from AFR 173-13 (USAF Cost and Planning Factors). Finally, information on the deployment and support scenario for the system, needed for the logistics factors file, is obtained from AFLC and the using command.

Shortcomings of the Model

The LCCH model has a number of shortcomings which limit its usefulness both as an estimating and tradeoff analysis tool. These deficiencies are explained below.

Inflation Adjustment. The LCCH model presents its costing information for each cost element covered by the model in two separate cost categories--undiscounted cost and present value cost. In the latter case, the model correctly discounts constant (current fiscal year) dollars by the Government discount rate detailed in AFR 173-15 (Economic Analysis and Program Evaluation for Resource Management) to arrive at a present value estimate of future cash flows. However, the term "undiscounted cost" is misleading owing to the fact that it does not represent the then-year (budget) dollar cost of the system as would be expected. This is because the LCCH model does not apply an explicit inflation adjustment factor to constant dollar estimates.

If the model user wishes to account for the effect of inflation on constant year dollars, he must either adjust the discount rate or apply an inflation adjustment factor outside the model.

Potential for Abuse. The proponent of the LCCH model, ALD/LSS, emphasizes the fact that the model should not be for preparing program cost estimates because its cost element structure (CES) does not conform to CAIG requirements for O&S cost estimates, and even within the cost elements covered

by the model, e.g., depot level maintenance, not all relevant costs are addressed (103). In fact, ALD/LSS recommends that the model only be used for conducting tradeoff studies because, in these cases, emphasis is on relative rather than absolute costs.

Notwithstanding this, the user's manual for the LCCH model does not explicitly warn against using the model for preparing cost estimates. Consequently, it is quite possible that an unsuspecting user may misapply the model and prepare an invalid cost estimate.

Software O&S Costs. While the predecessor of the LCCH model, the LCC-2 model, was developed for the specific purpose of estimating the O&S costs associated with aircraft avionics systems, neither it nor its successors address one of the most important avionics O&S cost drivers--software maintenance. In 1979 it was estimated that over the lifetime of a piece of avionics software, the amount spent on software maintenance was approximately one and a half times that spent on the software development (70:297). In the intervening 12 year period avionics equipment and its operating software has become considerably more complex, making it highly likely that the ratio of software maintenance to development costs has also increased.

Warranty Assessment. The user's manual for the LCCH model claims that one of the strengths of the model is its ability to be used to make an assessment of the cost

effectiveness of a weapon system warranty. While acknowledging that the ability to address the warranty issue is a worthwhile endeavor, the assumptions made in the LCCH warranty option make it inappropriate for use in the majority warranty assessment analyses.

For instance, the LCCH model assumes that the Government is offered only one specific type of warranty in all cases. This warranty specifies that:

1. All depot maintenance costs during the period of the warranty are paid for by the contractor.

2. The Government does not incur any initial training costs, initial and recurring item management or technical data acquisition costs, or support equipment maintenance costs, at the depot level, while the system is under warranty.

3. The Government incurs all shipping charges associated with moving reparable items to and from the contractor's depot maintenance facility during the period of the warranty.

In reality, quite different cost sharing arrangements are often agreed to by the Government and the contractor. In many cases, the warranty also covers failures that occur on warranted parts at the base repair level, and transport costs to and from the contractor's maintenance facility are shared by the two parties. Additionally, some depot maintenance during the warranty period will be at Government expense

owing to the nature of the failures that occur. The lack of flexibility in the LCCH's warranty option limits its usefulness.

Level of Detail. The LCCH model, like most accounting model's, requires an extensive amount of data to operate. Usually the level of detail needed on a system is not available until after Milestone III in the acquisition process. Consequently, although the model's proponent suggests that one of its primary uses is in tradeoff studies, the model's considerable data requirements mean that it has limited usefulness in the conceptual planning and design phases of a new weapon system, when the majority of future O&S costs determined. Additionally, the usefulness of the LCCH model in tradeoff studies is restricted by virtue of the fact that it computes O&S costs as a function of system R&M characteristics, such as MTBF, rather than directly relating these costs to performance and design parameters, such as speed and material composition.

The LCCH model's usefulness is further handicapped by virtue of the fact that it requires a full system hardware breakdown at the replaceable unit level before it can be employed. Unlike the LSC model, it does not use SRU factors to estimate spares requirements, and shipping and maintenance costs when full details of the SRUs comprising an LRU are not known. This means that the number of replaceable units covered in a model analysis must be restricted or employment

of the model delayed until a full system description is available.

Missing Factors. Although the LCCH model employs a considerable array of standard cost factors in preparing O&S costings, it omits several factors which have considerable bearing on sparing costs; namely "churn" factors, engineering change order (ECO) factors and out of production (OOP) factors. Churn is the term used to describe higher than anticipated demand for condemnation spares during system phase-in because of fluctuations in demand rates and configuration changes in existing spares items owing to modifications (1:Sec V,8). Studies by AFLC indicate that churn's affect on replenishment spares requirements may range from 150 percent to 250 percent of anticipated demand during system phase-in (1:Sec V,8). Similarly, ECO factors should be applied to allow for costs that are incurred during production years when changes to the physical, performance or logistics characteristics of a weapon system necessitate changes to components and, therefore, spares requirements. The factor should be applied to cumulative total spares costs because the cost of performing configuration changes applies to spares already produced (1:Sec V,5). Finally, OOP factors account for increases in the unit price of reparable items that are incurred when a production line must be reopened to maintain supply (93:Sec 3,23). When spares are purchased

intermittently in small batches, the OOP effect can greatly increase their cost (1:Sec V,7).

Although the cumulative effect of the above mentioned factors varies from weapon system to weapon system, allowance should be made for them in calculating spares costs because of their significance and variability.

Use of System Availability Measure. The LCCH model uses a system availability objective (AO) to determine initial spares acquisition requirements. For example, at the base level, the level of LRU spares required is computed in an iterative fashion by starting with zero spares and adding one LRU at a time until the system availability objective is reached (42:Sec 2,17). However, the use of the term "system availability" is a misnomer in this case because what the availability equation is actually computing, by comparing the expected number of LRU backorders against the total number of systems to be employed at a particular base, is a measure of supply effectiveness, similar to fill rate, rather than a strict availability measure. Actual system availability is a function of both supply and maintenance effectiveness, and takes into consideration the impact of corrective and preventive maintenance.

Marginal Analysis Technique. As mentioned previously, the LCCH model calculates initial spares requirements in order to meet a system availability objective. It does this using an iterative marginal analysis technique (42:Sec 2,19).

At the base level, for instance, the type of LRU added at each iteration is the one that provides the maximum reduction in expected backorders (42:Sec 2,18). Once the LRU has been selected, system availability is recalculated and tested against the specified system availability objective (AO). The user's manual indicates that "If the objective is met, no additional spares are required and the iterations terminate" (42:Sec 2,20). While the methodology used in the marginal analysis technique is itself sound, the method does not achieve an optimum SRU/LRU mix, from a financial investment viewpoint, because it does not take into consideration the relative cost of spares. Under the present method, an expensive component is treated no differently than a cheap spare in deciding which item to purchase to achieve the system availability objective.

A more appropriate marginal analysis technique would take the cost of spares into consideration and choose the LRU/SRU that achieved the maximum reduction in backorders per dollar spent. This method is currently used by the DO41 Aircraft Availability Model in calculating replenishment spares requirements (1:Sec IX,16). A modification to the LCCH model to accommodate this change in the marginal analysis method should be relatively easy to code, and information on the cost of LRUs/SRUs is already available in the hardware definitions file.

Maintenance Level Comparisons. The LCCH model allows the user to model two or three-level maintenance concepts or a combination of both over the life of a system. The model's "default" maintenance scenario is two-level maintenance applied while the system is under warranty and then, after warranty expiration, three-level "organic" maintenance. The ability to model centralized intermediate level maintenance was added to the LCC-2 model by DRC during its 1979 enhancement project (62:Sec 2,1). Owing to the fact that the LCCH is, principally, a trade study model, the capability to model other maintenance scenarios would be a particularly useful addition. Furthermore, such a capability would make alternative maintenance concepts available to all model users and avoid the need for cost analysts to make needed, but unauthorized, changes to programming code.

Commonality. Commonality is said to exist when a reparable item is used simultaneously by two or more different weapon platforms. Often, in such cases, economies are achieved through weapon systems sharing the same supply routes and maintenance procedures. Currently, the LCCH model does not have a explicit capability to handle item commonality. The model can be used in analyses that involve common items, by performing multiple runs, but the results do not reflect any likely economies in the use of supply or maintenance resources. Commonality would be a useful feature for the LCCH model to possess because avionics systems on

different aircraft quite often share common components, e.g., F-16 and F-15 inertial navigation systems (27).

Maintenance Manpower Calculations. The LCCH model uses three separate equations to estimate the cost of flight-line, base and depot level maintenance (42:Sec 2,27-29). Average maintenance manhours is a variable in each one of these equations. While such calculations are useful for tradeoff study purposes, they do not reflect the true cost of maintenance because total maintenance manhours do not equate to the level of maintenance manpower needed to carryout repair work. This inequality occurs due to the fact that maintenance is cyclical in nature and, therefore, demand rarely equals maintenance capacity, and also because a substantial portion of the Air Force maintenance workforce is undergoing training at any particular point in time and, consequently, is not fully productive. Additionally, leave and sickness periods must also be taken into consideration. Consequently, a derating factor is usually applied to maintenance manpower to arrive at a net productive worktime (124:Ch 7,7). May suggests a method for converting total maintenance manhours to actual manpower requirements using a derating factor (124:Ch 7,7). This technique allows standard AFR 173-13 cost factors to be employed to arrive at a more realistic total maintenance manpower cost.

Model Input/Output. The LCCH model uses standard ASCII format to build and manipulate the five input data files.

This method is time consuming and cumbersome and does not allow the user to easily set-up or change large files. Data entry would be considerably improved if the model could use standard spreadsheet or database input file formats.

Moreover, output formats cannot be manipulated by the user to perform supplementary analyses. Quite often, output data has to be manually transferred to a spreadsheet to allow the application of inflation factors needed to convert "undiscounted costs" to then-year values.

User's Manual. The user's manual for the LCCH model needs to be rewritten in a consolidated format. At present, the manual is a conglomerate of separate research efforts by different organizations and reads in a disjointed manner. It is not a particularly easy manual for first time users to follow. More specifically, the manual lacks a consolidated list of assumptions and cost element equations (at present the user is forced to flip between the DRC supplement and the original TASC manual to obtain equation information), it does not explicitly warn the user about how the model can be misapplied, and it does not fully explain the basis for a number of equations.

Model Maintenance and Use Costs

The PC version of the LCCH model is designed to run on an IBM-compatible microcomputer. Because Z-248 microcomputers are used throughout the Air Force, for a variety of

purposes, the variable costs associated with running the PC version of the LCCH model are negligible. The LCCH model requires that the cost analyst build new input files for each separate analysis. The gathering of the information necessary to build these input files takes the majority of the analyst's time. ASD/ALT, one of the main user's of the LCCH model, estimates that it can take an experienced analyst anywhere up to a month to gather the needed information, depending upon the size and complexity of the trade studyoff being performed. A similar period is required to validate the data gathered, input it into the model, perform sensitivity analyses and document the findings (27). An ASD/ALT analyst is typically a Capt/Major or GS-12/13 equivalent with an average composite salary in the vicinity of $5000 per month (102). Accordingly, the direct manpower costs associated with preparing a tradeoff study or warranty CBA using the LCCH model is in the vicinity of $10000. While this is considerably less than the analyses prepared using the LSC model, it is important to remember the different purposes of the two models. The LSC model is used to prepare cost estimates and ICAs for CAIG submission which require considerably more information than the tradeoff analyses performed using the LCCH model.

There is little contractor involvement in the use of the LCCH model, as the majority of tradeoff studies and warranty CBAs performed using the model are done by "in-house"

personnel. The exception to this rule is where a SPO may hire a contractor, because of staff shortages, to act as system engineering technical advisor (SETA) and the contractor uses the model in tradeoff studies (103).

At present, very little maintenance is performed on the LCCH model. The LCCH model has not been validated and, owing to funding constraints, is unlikely to be validated in the foreseeable future. Furthermore, with the CAIG edict that only validated cost models be used in submissions to the DAB (39), the future of the model is uncertain. The proponents of the model, ALD/LSS are presently evaluating whether it might be worthwhile incorporating the better features of LCCH in the LSC model, in order to allow the continued conduct of tradeoff studies, or abandon use of the model altogether (103).

Benefits of Model Use

Decisions Made Using Model. The LCCH is used in tradeoff studies involving hundreds of millions of dollars worth of equipment and its analysis results can influence which competing design alternative is chosen (103).

Beneficial Model Characteristics. Notwithstanding the criticisms of the LCCH model made earlier, the model is still a useful tradeoff study tool. The model has a number of good features which make it useful for calculating selected O&S cost "figures of merit" that permit the ranking of design

alternatives. For example, the hierarchical structure of the model's hardware file makes the model sensitive to changes in replaceable unit reliability parameters and allows a assessment of such changes on system availability. The LCCH model also estimates base and depot reparable item safety stocks; considers the impact of part shortages on base and depot repair cycle times; allows a change in maintenance support approach partway through the life cycle of a system; accommodates reliability growth in components during system operation; allows discounting of outlay streams and has a significant sensitivity analysis capability. Furthermore, although data collection requirements for the operation of the model are significant they are not unreasonable in terms of the demands they place on the time of the cost analyst.

Sensitivity Analysis Capabilities. As mentioned previously, the LCCH model has significant parameter modification and sensitivity analysis capabilities. Once information has been entered into the relevant input files using a text editor, the mainframe version of the LCCH model has menu options which allow "on-screen" modification of all system variables and range analysis of selected sensitivity variable (one at a time) (42:Sec 3,4-10). All but a few variables in the hardware definitions file can be changed during sensitivity analysis and access to these parameters is only restricted because their variation might result in

inconsistencies within other parameter files, e.g., number of replaceable units.

Unfortunately, the PC version of the LCCH model, while having the same basic capabilities, is not as user friendly as the mainframe version in the way it allows the options to be exercised. In the PC model, the user must enter parameter modification and sensitivity information into a control file off-line, using a text editor, and then run the program in the control file mode (4.:Sec 3.10-11). Another problem with the model's sensitivity analysis option is that the user can quickly become inundated by the amount of data that can be generated using the facility. Moreover, the model does not have the ability to interface with either a spreadsheet or graphics package to allow the results to be quickly analyzed, thereby limiting the usefulness of the data output.

Model Improvement and Validation

Neither the LCCH model nor its predecessors, LCC-2A and LCC-2, have been formally validated. Accordingly, it is difficult to make an assessment as to whether the changes in the model have resulted in "improvements". Additionally, because the model should only be used in tradeoff studies, and not for preparing cost estimates, one cannot draw a conclusion about whether subsequent modifications have improved the model's estimating ability or not. Consequently, in order to make an assessment of whether

changes to the model have been for the better or otherwise, it is necessary to examine the circumstances surrounding particular modifications.

The first series of modifications to the LCC-2 model developed by TASC in 1976, were carried out by DRC in 1979. These changes were made in response to perceived weaknesses in the original model, e.g., errors in cost computations and the model's inability to compute desired support approaches (62:Sec 1,1). To the extent that these specific problems were overcome by the program modifications, the changes could be considered an improvement. The second and less extensive change to LCC-2A (as LCC-2 became known after DRC's efforts) was made by Mr John Huff of ASD/LSS in 1985. This modification involved a coding change to designate "pipeline spares" as an acquisition cost and "condemnation spares" as an O&S cost (LCCH 42:Forward). This change was made in response to a CAIG recommendation that the two types of spares be separated for funding purposes (10:24). Previously, LCC-2A had considered all spares as acquisition items. This revision of the model, which became known as the LCCH, was a definite improvement because it provided a better representation of the "time value" of the spares funds involved. The present worth of spares under LCC-2A was equal to their procurement cost in the year of system procurement. However, because in actual fact condemnation spares are not purchased until after a system has been in operation for a

period, their present value will differ from that in the former case (103).

The most recent change to the LCCH model occurred in 1986 when it was rehosted on a microcomputer. Despite some loss in user friendliness that occurred in the transition, the move could be considered an improvement by virtue of the fact that it improved analyst access to the model. The fact that ASD/LSS has distributed over 500 copies of the model since it was rehosted lends support to this conclusion (103).

The ZCORE Model

Background of the Model

ZCORE is the ZBASIC version of the Cost Orientated Resource Estimating (CORE) Model described in AFR 173-13 (USAF Cost and Planning Factors) (50:1). The CORE model has its origins in the Planning, Programming and Budgeting Annual Cost Estimating (BACE) and Cost Analysis Cost Estimating (CACE) models detailed in AFR 173-10, the planning factors guide that preceded AFR 173-13. These two models broadly covered aircraft squadron variable O&S expenses and recurring investment costs (122:19). More specifically, BACE was used to generate estimates for exercises conducted as part of the Planning, Programming and Budgeting System (PPBS), and the CACE model was used in "cost or research analyses, life cycle

cost exercises, or studies concerned with cost effectiveness comparisons between weapon systems" (48:Sec 2,15).

In 1980, when AFR 173-10 was superseded by AFR 173-13, the BACE and CACE cost factor models were dropped from the regulation and the CORE model was substituted in their place. CORE directly replaced CACE as the LCC model and, subsequently, the Systematic Approach to Better Long-Range Estimating (SABLE) Model was developed to fill the gap left by BACE's withdrawal. SABLE, which has a cost element structure very similar to the CORE model, was developed specifically to provide the Air Staff "with a tool to cost force structure changes quickly and accurately" (49:30). CORE presents its estimates in constant year dollars, whereas SABLE uses then-year dollars (49:31). The need to revise the aircraft squadron O&S models was prompted by the publication, for the first time, of a standard set of O&S cost categories by the OSD CAIG (49:30).

CORE is a manual model comprising a number of cost factor equations. The first attempt to automate CORE was undertaken in 1981 when AFLC sponsored DCS Management Sciences to develop a version of the model that could be programmed on a hand held calculator (119:150). Then, in 1986, Lt Fifer and Capt Stearns of ASD/ALT computerized CORE so that it could be used on a Z-100 or Z-248 microcomputer. The computerized version of CORE became known as ZCORE

Version 1.0. The latest revision of ZCORE, Version 2.0, was released by ASD/ALT in 1988.

Purpose of the Model

ZCORE is a computer based extension of the CORE model described in AFR 173-13. CORE was designed to provide the major commands (MAJCOMs) with a cost estimating model that could be used to develop aircraft squadron O&S cost estimates (49:26). The CORE model, or some variant of it, is also frequently used by SPOs, contractors and Air Staff offices to generate system O&S costs. AFR 173-13 notes that CORE is a variable cost model, and, as such, estimates for its cost categories do not necessarily correspond to those shown in the PPBS. However, many of the model's cost elements are compatible with approved PPBS costs, and can be used to assess the impact of alternative aircraft choices (49:26).

General Characteristics of Model

Version 2.0 of the ZCORE model has 125 cost factors segmented into eight primary cost categories. These eight cost categories are:

1. Unit Mission Personnel,
2. Unit-Level Consumption,
3. Depot-Level Maintenance,
4. Sustaining Investment,
5. Installation Support Personnel,
6. Indirect Support of Personnel,

7. Depot Nonmaintenance, and

8. Acquisition and Training. (49:26-30)

In general, there is little difference between ZCORE and the CORE model detailed in AFR 173-13. Both models use as primary inputs Primary Authorized Aircraft (PAA) per squadron, annual flying hours (FH) per aircraft and manpower requirements per squadron, and multiple these values by a number of other factors to generate "typical squadron operating and support costs" (49:28). However, ZCORE has expanded slightly on the number of cost factors identified in the CORE model by adding additional factors for base level contractor logistics support (CLS) per flying hour and base level CLS per PAA (50:2). The user's manual indicates that these enhancements are "intended to increase the utility of the traditional CORE model" (50:2).

The cost factors themselves are generated and maintained by the Air Force Cost Center (AFCSTC) using information from a variety of Air Force databases and input from user Commands (49:6). A number of the factors are generated using statistical regression techniques. The factors are updated on a quarterly basis, if needed, by AFCSTC (49:7). In response to changes in the regulation factors, ASD/ALT update the ZCORE model to reflect any changes that effect the model.

Model Assumptions

The user's manual of the current version of ZCORE does

not identify any explicit assumptions made by the model. However, the main assumption implicit in the use of any factor model, including ZCORE, is factor congruence. Factor congruence means that the factors used in estimates (which themselves are derived from historical data) are representative of the system being investigated. Accordingly, if a weapon system is radically different from its predecessors, factors need to be adjusted or a different estimating approach adopted.

Uses of the Model

The user's manual for version 2.0 of the ZCORE model indicates that the model has potential for use in the following areas (50:1):

1. weapon system comparisons,
2. programming exercises,
3. Independent Cost Analyses (ICAs), and
4. preparing O&S baseline estimates.

Weapon system comparisons carried out using the model include analyses done as part of the contractor source selection process, as well as general tradeoff studies. For example, the model was recently used in a trade study comparing two different proposed replacement engines for the F-16 (27). Modification cost-effectiveness studies are also conducted using the model. Typical programming exercises include analyses of the cost of relocating an aircraft

squadron or augmenting activity at a particular base. The model is also used in determining O&S cost baselines for major new weapon systems, required by DODD 5000.45 (Baselining of Selected Major Systems).

In addition to the above, ASD/ALT also uses the model for conducting warranty cost benefit analyses, and for performing the O&S portion of Cost and Operational Effectiveness Analyses (COEAs) required by DODI 5000.2 (Defense Acquisition Management Policies and Procedures) as part of the major weapon system acquisition process (27).

The user's manual also warns about the possible misapplications of the ZCORE model. In particular, it cautions users that the model is general in nature and not applicable to every system, and, because of the fact that it considers only variable O&S costs, should not be used for budgetary purposes (50:1).

Model Data Sources

The planning factors contained in AFR 173-13 are the primary data source for the ZCORE model during the preparation of estimates early in the acquisition process. However, AFR 173-13 indicates that input information can be taken from the regulation or developed independently (49:26). In fact, AFR 173-13 encourages the user to take advantage of more detailed information as it becomes available during program progression. The regulation highlights the fact that

the model's hierarchical cost structure, i.e., where each lower set of indentured cost elements sums to equal the next higher indentured element, "allows flexibility in selecting the level and method by which an element is estimated" (49:26). The ZCORE model's structure allows it to be used during the early stages of an acquisition program, when only aggregate cost information is available, and it can evolve to accommodate more detailed information as the program progresses. However, the regulation also specifies that if an analyst chooses to use an alternative estimating method it should be thoroughly documented (49:26).

Shortcomings of the Model

The main shortcomings of the ZCORE model relate to its limited usefulness in predicting the effect of changes below the system level. These difficulties are inherent in all factor type models. Specific model problems are discussed below.

Factor Level Limitations. All the factors used in the ZCORE model are only available at either the system (aircraft level) or subsystem (eg engine, airframe) level of aggregation (49:187-189). Consequently, because the model does not "break-out" costs in detail at the LRU level and below, it is not particularly useful for capturing the O&S cost impact of individual R&M characteristics that are peculiar to a new weapon system (23:14). Similarly, there is

no provision in the model to vary resource inputs, e.g., manpower, as functions of system characteristics or O&S concepts (122; 79:20).

Limited Sensitivity Capabilities. Closely related to the cost factor limitations of the ZCORE model are its sensitivity restrictions. Firstly, the O&S costs predicted by the model are not sensitive to system performance and design parameters because no such characteristics are factored into the model. This deficiency limits the usefulness of the model for design tradeoff purposes early in system conceptual planning and design when the majority of tradeoff decisions, which subsequently affect LCC, are usually made. Secondly, the model has no specific sensitivity analysis feature in its output module. Sensitivity analysis is currently performed by the analyst changing specific inputs on different runs of the model.

Data Problems. The cost factors used in the ZCORE model are derived from, or are an extrapolation of, data from the cost history of existing weapon systems. Aircraft are usually grouped into common mission series before factors are extracted. In this way, aircraft with approximate design characteristics are considered together and, in theory, a more representative factor is derived. There are two possible limitations in this method. Firstly, the factors determined using the technique are only as good as the accuracy and validity of the information used to derive them.

The AFCSTC extracts information from numerous Air Force databases in order to calculate cost factors as well as obtaining information from user commands. Therefore, considerable scope exists for there to be inconsistencies between databases and, as a result, factors may have limited accuracy. It could be argued that this inaccuracy is of little concern because ZCORE is only used for preparing comparative estimates, and the effect of errors is likely to be consistently distributed amongst the alternatives being investigated (and therefore "order of merit" is maintained). However, this may not be the case if one design is radically different from other alternatives and significantly different emphasis is placed on particular inaccurate cost factors.

Similarly, factor models are not particularly affective in accounting for significant differences in technology between the analogous group of weapon systems and the new system being investigated. Consequently, O&S costs may be significantly under or overestimated and the relative rankings of design alternatives can be changed by the effect of technology.

Consideration of Aircraft Availability. The ZCORE model does not address the issue of aircraft availability.

Model Input/Output. Like the LSC and LCCH models, ZCORE does not use spreadsheet or database input/output interfaces to smooth the entry and manipulation of data. Data can be input into ZCORE in one of two ways--interactively or using

an ASCII data file (50:12). In the latter case, a text editor must be used to form an ASCII data file. Consequently, the user must either be familiar with the model's operation or pay close attention to the user's guide to ensure data is entered in the correct format, as a number of factors are derived by ZCORE using other factor inputs (50:12). The interactive mode is much more user friendly and walks the analyst through each step in entering data. Unfortunately, this method is not particularly time efficient when a large amount of data has to be entered. A useful compromise would be to allow data to be entered into a spreadsheet template, where the user could see the derived values calculated, and then have the information transferred to the model.

Similarly, on the output side of the model, although ZCORE has a number of report options, output formats cannot be manipulated further by the user to perform additional analyses. If additional analyses are required information must be manually transferred to a spreadsheet.

Model Maintenance and Use Costs

As mentioned previously, ZCORE is a microcomputer based model that runs on standard USAF Z-100 or Z-248 terminals (50:3). An analyst is required to build a new data file containing factor information for each estimate prepared using the model. The data file may be build prior to running

the model using an ASCII text editor or created interactively during a session (50:12).

The speed with which an estimate can be prepared is one of the main advantages associated with using a cost factor model, and ZCORE is no exception. ASD/ALT, the proponent and maintainers of the model, estimate that the average time taken to prepare an estimate using ZCORE ranges between one and two weeks. This is considerably faster than accounting type O&S models. The estimating period, however, is directly proportional to the number of standard factors able to be used in the model. If the system under investigation is significantly different from existing systems in the same mission category, few factors may be applicable and, consequently, a substantial amount of data may need to be collected outside the model. This will slow down the speed of a ZCORE estimate considerably.

ASD/ALT also has an analyst working part-time on maintaining and improving the model. This person answers queries from users in the field and modifies the model, when necessary, in response to any AFCSTC initiated changes in CORE model factors published in AFR 173-13. Furthermore, the analyst is currently rewriting ZCORE in Turbo Pascal in order to improve its user friendliness and presentation qualities (134).

Benefits of Model Use

Ease of Use. The prime benefit of ZCORE as a cost factor model is its ease of use. The information needed to operate the model is readily available in AFR 173-13, and the cost factors themselves can be updated periodically to reflect the Air Force's most recent O&S cost experience. Accordingly, estimates can be prepared relatively quickly using ZCORE compared to accounting type O&S models.

Comprehensive Coverage of O&S Costs. Owing to its nature and the relative speed with which it is able to prepare estimates, ZCORE is able to address a number of O&S cost elements which are not included in other model, e.g., Class IV modification costs and replacement support equipment. The use of cost factors also means that the model can be used relatively early in the acquisition process when only aggregate system information is available. However, as noted earlier, its ability to address specific performance and design related R&M issues is also limited by its aggregate nature.

Model Improvement and Validation

The ZCORE model has been updated once since its original release in 1986. The current version of ZCORE, Version 2.0, replaced Version 1.0 in 1988. The major changes from Version 1.0, in the latest edition, were the addition of a menu structure to allow the user to move more freely between the

different program modules of the model, and the inclusion of two new factors relating to base level contractor logistics support (CLS). AFR 173-13 describes CLS as:

> a permanent method of contractor support for short operational life systems and ... a method of providing all or portions of the organizational, intermediate, or depot support required to support a weapon system. (50:2)

Previously, base level CLS had been included under the Depot Maintenance cost element (50:2), thereby misrepresenting the magnitude of the latter cost component. The above changes represent definite improvements to the model. The menu change is also significant because it makes the model more efficient to use as well as more user friendly, and the factor change is an improvement because it allows base level CLS, an important cost element, to be modeled more accurately.

A new version of the ZCORE model, written in Turbo Pascal, is planned for release in July 1991. This version will have the same menu structure as ZCORE 2.0, but will take advantage of Turbo Pascal features to make the model more user friendly, e.g., window defined menus with highlighted scroll bar selection of options. Additionally, it is intended that the new version of the model also have a sensitivity analysis option on its output menu, thereby removing the need to modify ASCII files and re-run the model in order to test the sensitivity of particularly system parameters (134).

The ZCORE model has not been formally validated in the same sense as the LSC model, i.e., by a distinct validation study. However, the model's proponent consider that it has a valid foundation because it is a direct translation of the AFR 173-13 CORE model, and the planning factors used in the model are themselves derived from actual Air Force O&S cost data and are updated on a regular basis (27).

IV. Multi-Phase LCC Models

Chapter Overview

This chapter reviews a group of models that provide a more complete coverage of life cycle costs than the models detailed in chapter three. In fact, the models address costs in three of the four LCC phases, namely, research and development, acquisition, and O&S. The models reviewed include the Defense Systems Management College's Cost Analysis and Strategy Assessment (CASA) model; the General Electric Parametric Review of Information for Costing and Evaluation (PRICE) family of models, including the hardware, hardware life cycle, microcircuit, and software cost models; and the Grumman developed Modular Life Cycle Cost (MLCC) model. Both the PRICE models and the MLCC model can be categorised as typical parametric models. On the other hand, the CASA model cannot be fitted neatly into any one of the classes described in chapter two. This is because CASA consists of a number of different modules, each having different features. Put simply, CASA is an optimization model that has simulation capabilities and aggregates costs like an accounting model.

The CASA Model

Background of the Model

The major portion of the initial version of the model

that was eventually to become known as the Cost Analysis and Strategy Assessment (CASA) model was developed for the Defense Systems Management College (DSMC) by Honeywell in 1986. The model was based on Honeywell's Total Resource and Cost Evaluation (TRACE) 2 Personal Computer (PC) model, a member of the TRACE family of logistic and LCC models (52:Sec 1,1; 105:30). In addition to Honeywell's efforts, DSMC also enlisted the help of Resource Sciences Inc. to enhance the "user friendliness" of the modified TRACE model by adding a screen-orientated data entry management program and revising the documentation to make the model's functions more understandable for logistics managers (105:30).

The original CASA model was written in Fortran and consisted of the following computer programs (52):

1. a LCC analysis program;
2. a LCC sensitivity analysis program;
3. a Monte Carlo simulation LCC program;
4. a risk analysis program;
5. a program that outputs a consolidated list of input information;
6. a program to compare the outputs of two different CASA LCC runs; and
7. a screen-orientated program designed to elicit input data from the user interactively (thereby eliminating the need for a general-purpose text editor), and create and edit CASA LCC and risk data files.

The user friendliness of CASA provided a stark contrast to the majority of LCC models available at the time and this coupled with the wealth of analysis features available on the model encouraged its use in all branches of the services. However, the early version of the model had several limitations which restricted its more widespread application. Firstly, the model had a limited ability to handle prime hardware items. Users could, at most, describe 98 LRUs or SRUs in an analysis. While this was adequate during the early stages of a system's development, as the system matured and more detailed information became available on hardware the capacity of the model was soon exceeded. A larger project could be segmented and analyzed using separate runs of the model, but CASA had no facility to aggregate the cost information at the completion of the exercise. Consequently, the model was relegated to handling relatively minor projects. (125:10). Additionally, the model did not address research, development, test and evaluation (RDT&E) or software costs, and had only limited sensitivity analysis capabilities (only three key variables could be examined--unit cost, MTBF and MTTR).

To overcome these problems and encourage greater usage of the model, DSMC sponsored a major upgrade of the model. This upgrade was completed by EG&G Inc. in 1990 and Version 2.0 was released in spring of that year. The revision comprised the following changes (91):

1. The computer language in which the program was written was changed from Fortran to Microsoft C to allow the incorporation of a more "user friendly" interface. It also allowed color to be added to the model as well as menu windows.

2. RTD&E equations were added to allow the model to provide a more complete LCC estimate.

3. A software cost estimating capability, based on the Software Cost Estimating Model (SCEM) (which is itself a variant of the Constructive Cost Model (COCOMO)), was added to the model (53:Annex B,36).

4. The number of LRUs able to be handled by the model was expanded from 98 to 175 to allow larger projects to be considered.

5. A Comparison/Summation option was added to allow comparison of the differences between two LCC runs of the model and/or a summation of the cost of two or more LCC runs.

6. A number of new format options were added to the model's output module to make it more flexible and usable.

7. The model's sensitivity analysis capabilities were also significantly enhanced (from three to 17 input parameters) (53:Sec 3,8).

8. A facility to convert CASA Version 1.0 data files for use in the new model was also provided (91).

The most recent version of CASA, Version 2.01, was released shortly after Version 2.0 in August 1990 to correct

some minor programming faults in the previous version of the model (91).

The enhanced user friendliness of the updated version of CASA accentuated the difference between itself and more traditional logistic cost models and encouraged further use of the model. As mentioned previously, the model provided color displays and "pop-up" menus as well as an extensive on-line "help" system. In addition, the user was provided with considerable menu assistance in entering and editing data, and formatting model output. Finally, an extensive and easy to use sensitivity analysis capability was provided to allow measurement of the impact of changes in key parameters on LCC and system operational availability. CASA was also different from other models in that it attempted to cover the entire life cycle of a weapon system (excluding disposal), and not just focus on a particular portion of it like the majority of other LCC models.

The result of these endeavors is that CASA has become a "benchmark" for the revision of other LCC models such as LSC, ZCORE and STEP.

Purpose of the Model

The most recent version of CASA was designed to be a complete LCC model that could also perform "risk, sensitivity and data comparison analyses" (53:Sec 1,1). It considers RDT&E costs, acquisition costs and O&S costs over the

economic life of a weapon system (53:Sec 1,1). CASA was specifically developed to be an "analyst's tool module" in the Program Manager's Support System (PMSS). PMSS is a series of integrated software programs designed by DMSC to assist acquisition logistic executives, managers and analysts in decision making processes (53:Forward).

General Characteristics of Model

The user's manual for Version 2.01 of the CASA model suggests that CASA "incorporates various analysis tools into one functioning unit" (53:Sec 3,1). More specifically, it allows the system user to generate data files; perform LCC, sensitivity and risk analyses; compare various LCC runs and summarize the results in graphical and tabular formats (53:Sec 3,1). A number of data editing features are also provided. Figure 6 illustrates how the these programming modules are related.

Functional Description. The structural logic of CASA has been designed to imitate the process used by cost analysts in assessing the feasibility of various alternative courses of action (53:Sec 3,2). The program structure mirrors the general divisions in this process. The divisions are (53:Sec 3,2):

1. File Creation--entering basic data on the system to be studied.

2. System Attributes--entering technical data on the

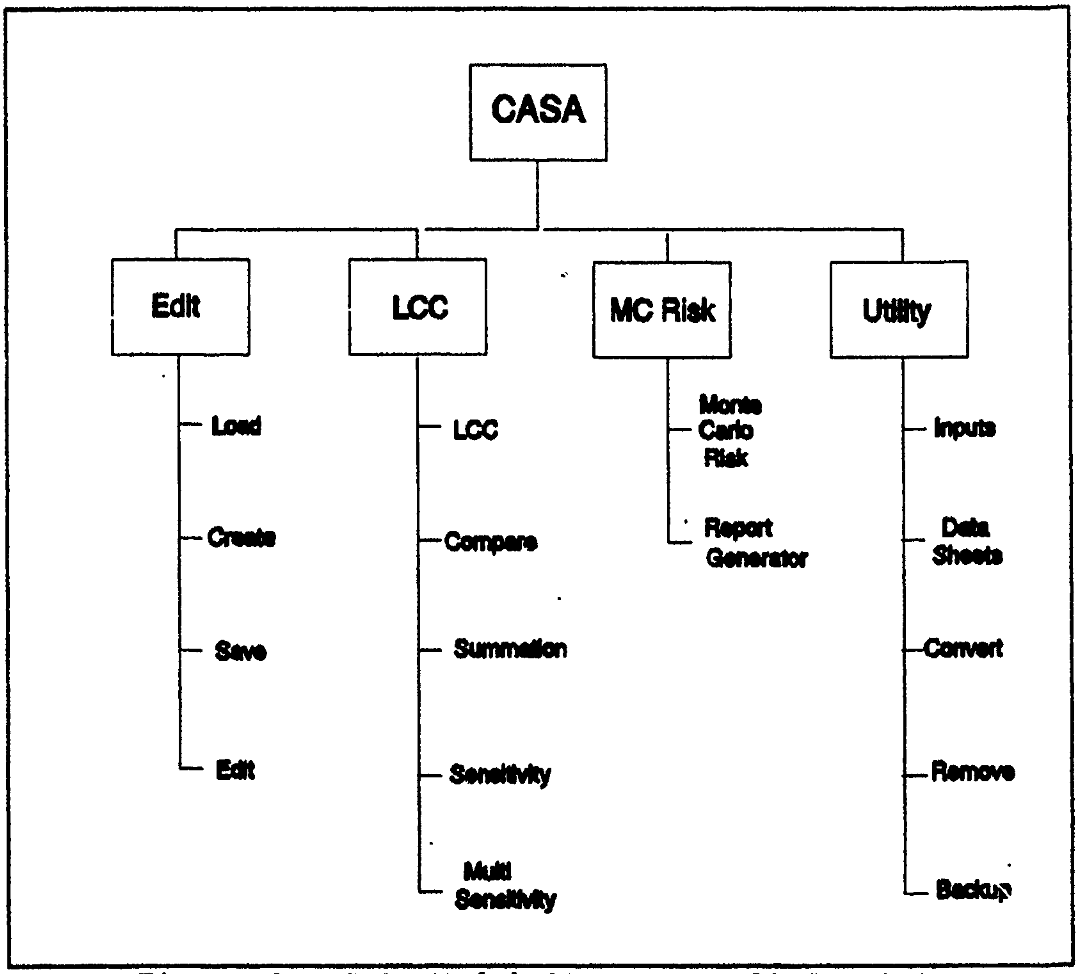

Figure 6. CASA Model Structure (53:Sec 3,1)

system in order to permit LCC runs.

3. Cost Analysis--calculating the LCC of the system.

4. Change Inputs--altering input data and measuring the effect of the changes on the system cost structure.

5. Risk Analysis--defining risk levels and calculating the probability of achieving, falling short or exceeding any "baseline" LCC target.

6. Sensitivity Analysis--altering hardware, maintenance or other system parameters and gauging their affect on spares

levels, LCC and weapon system availability.

7. Comparison and Summation Analysis--outputing comparison and summary tables for various LCC runs.

8. Multiple Sensitivity Analysis--conducting sensitivity analysis on multiple LCC data files.

CASA LCC Module. The LCC module of CASA develops cost projections for three phases in the life cycle of a weapon system: the RDT&E phase, the acquisition phase and the O&S phase. These three phases are broken down into the 34 subsidiary cost categories shown in Table 1. Resource quantities and costs are tallied within each cost category for each year of the analysis (53:Sec 2,1). The LCC module also, optionally, evaluates warranty usage and calculates the number of each type of LRU needed at the organizational level to achieve the highest degree of operational availability given a certain spares budget (53:Sec 3,6). Additionally, owing to the fact that deployment changes may occur within a given year, the model permits the number of operating systems to vary from month to month.

Model Assumptions

The current version of the CASA model makes the following assumptions:

1. Calculations involving manpower, spares and support equipment are based on the maximum number of operating

TABLE 1

CASA COST CATEGORIES (53:Annex A,88)

ACQUISITION COST CATEGORIES

1. Tooling and Test Equipment
2. Start-Up
3. System Acquisition
4. Shipping Containers
5. Preproduction Engineering Changes
6. Preproduction Refurbishment
7. Installation
8. Support Equipment
9. Hardware Spares
10. Spares Reusable Containers
11. Initial Technical Data
12. Initial Training
13. Training Devices
14. New Facilities
15. Initial Team Management
16. Initial Software Development
17. Miscellaneous Acquisition Costs
18. Warranty

OPERATION AND SUPPORT COST CATEGORIES

19. Operating Labor
20. Repair Labor
21. Support Equipment Maintenance
22. Recurring Training
23. Repair Parts and Materials
24. Consumables
25. Condemnation Spares
26. Technical Data Revisions
27. Transportation
28. Recurring Facilities
29. Recurring Item Maintenance
30. Software Maintenance
31. Contractor Services
32. Engineering Changes
33. Warranty Cost
34. Miscellaneous O&S Costs

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systems available, whereas quantities involving maintenance actions are based on averages (53:Sec 2,1).

2. The operational availability sub-section of the LCC module does not consider indentured spares below the LRU level and LRU spares are only considered at the organizational level, not intermediate or depot repair levels. Additionally, MTBFs and system quantity figures used in availability calculations are taken from the most recent deployment year (53:Sec 2,2).

3. Not Mission Capable due to Supply (NMCS) rates are calculated using the expected number of LRU backorders at the organizational level (53:Sec 2,2).

4. Uncertainty in unit cost, MTBF and MTTR can be represented in the Risk Module by either a Normal, Triangular, Uniform or Constant distribution (53:Sec 3,10).

5. Total LCC is calculated as the sum of RDT&E, acquisition, and O&S costs. System disposal costs are not considered (53:Annex B,2).

<u>Uses of the Model</u>

The user's manual for Version 2.01 of the CASA model identifies a number of tasks on which the model can potentially be employed. These include:

1. LCC Estimates.
2. Trade-off Analyses.
3. Repair Level Analyses.

4. Production Rate and Quantity Analyses.

5. Warranty Analyses.

6. Spares Provisioning.

7. Resource Projections (e.g., manpower, support equipment).

8. Risk and Uncertainty Analyses.

9. Cost Driver Sensitivity Analyses.

10. Reliability Growth Analyses.

11. Operational Availability Analyses with Automated Sensitivity Analysis.

12. Spares Optimization.

13. Operation and Support Cost Contribution by Individual LRUs. (53:Sec 1,1-2)

The USAF does not use the CASA model in a number of these roles because it has specialized logistics models already available. For example, optimal replenishment spares requirements are calculated using the Aircraft Availability Model (AAM) within the D041 system (however, AAM employs an optimization technique very similar to CASA). The Aircraft Sustainability Model (ASM) is used to compute WRSK requirements and Dyna-METRIC is used to assess the operational capability of these kits. Similarly, the Air Force has a number of specialized RLA models designed for specific types of weapon systems, e.g., missiles (94).

The Air Force does, however, use CASA for maintenance concept analyses, e.g., whether it is more cost effective to use two-level, three-level or contractor logistic support

(CLS) for particular weapon systems or sub-systems. The F-16 SPO also uses CASA to assess the cost effectiveness of proposed aircraft modifications (111).

Model Data Sources

Owing to the fact that it is an accounting model, CASA has fairly extensive input data requirements. As noted previously, the three LCC phases used in the model are broken down into 34 data categories each requiring cost and resource information. The model requires that quite detailed information be available on system LRUs and manpower requirements before it can be used properly, although this point is disputed by some researchers (105; 123). The level of detail required precludes the model from being used in the concept exploration and design phase of a system's life cycle. However, once this information is available, the system has the potential to deliver a fairly detailed and accurate estimate.

Cost analysts obtain information from a variety of sources in order to operate the model. System operational scenario data is obtained from user commands, reliability data is obtained from contractors, and maintenance cost data is obtained from contractors or is developed using information on analogous systems from Air Force databases such as VAMOSC.

Estimates prepared using the CASA model rarely use classified data sources. The information required for use in CASA is not unique to the model and is fairly readily available once the system in question has reached a certain level of design maturity. Costs are input to CASA in constant dollars of the current financial year. However, the model has the capability to present the results of its LCC calculations in either constant, inflated, or inflated and discounted dollar terms. The user defines the inflation and discount rates to be used in each year of the analysis in a matrix format along with reliability growth information (53:Annex A,33). The model also has self-editing features which perform sanity checks on data input by the user. However, as always, the reasonableness of model output must be judged by the cost analyst.

Shortcomings of the Model

Operational Availability Estimate. The LCC module within CASA performs an "operational availability analysis" on the system(s) under investigation to inform the user of the portion of time that a system should be mission capable given the defined reliability, maintainability and supportability parameters (53:Annex B,80). However, in calculating its operational availability measure, CASA only analyzes LRUs and the system itself and these items are only considered at the organizational level. In limiting its

spares analysis to these higher indentured items, CASA underestimates the expected number of backorders and overstates the expected availability of repair items. It does this by ignoring the delay in the repair of higher indenture items caused by backorders on the items' lower indentured components, e.g., SRUs.

The model also overestimates operational availability by assuming that their are only two ways for a system to be down --"because a failed sub-system or LRU is being removed and replaced with a spare....[or] because of the lack of a needed spare" (53:Annex B,80). In reality, in addition to corrective maintenance, preventive maintenance also limits the amount of time a weapon system is available for operation. Preventive maintenance is not considered in the CASA operational availability equation.

Maintenance Concept Analysis Restrictions. The current version of the CASA model allows the user to model a maximum of three maintenance levels in an analysis. While this is useful for comparing the cost effectiveness of two versus three-level maintenance proposals, the capability to model other maintenance scenarios would be a useful addition to the model.

Design Tradeoff Limitations. Like most accounting type LCC models, CASA has limited usefulness during the critical concept exploration and design phase of a new weapon system because of the type and detail of information it requires to

operate. For instance, the model computes O&S costs as a function of component reliability parameters, such as MTBF and MTTR, rather than directly relating O&S costs to system performance and design parameters. Accordingly, the model generally cannot be used before Milestone II, unless their is an analogous weapon system on which to base the estimate.

Model Data Intensity. As mentioned previously, CASA is a fairly data intensive model, although not as intensive as O&S accounting models such as the LSC. It requires information in 34 separate cost categories and requires that the cost analyst have detailed information on system hardware and manpower requirements. However, this criticism of the model has been refuted by at least one researcher. Martin, for instance, found in a 1989 study investigating how microcomputer-based logistics models could be used to enhance the major project analysis capabilities of the USAF Productivity, Reliability, Availability and Maintainability (PRAM) Program Office, that Version 1.0 of the model had a good ability to "work off a limited data set and still produce workable results" (123:107). However, CASA does use an equipment orientated approach to building an LCC, i.e. it looks at how a system is built-up from the lowest structure and components. It requires therefore that a reasonable amount of information be available on the system in question. Indeed, detailed information is needed to take full

advantage of the considerable estimating power and analytical versatility of CASA.

Model Generality. The CASA model has been designed to be applicable to a wide range of LCC analysis situations. While the generality of the model is undoubtedly one of its strengths, it also limits the model's ability to address some special or unique project requirements. For instance, CASA is built around a clearly defined equipment maintenance scenario which is not always appropriate for some projects. Accordingly, the cost analyst must be wary in specifying input data in order to ensure that the final result is valid. For example, the model calculates the manhours needed for maintenance and repair and then computes staffing levels. The resultant maintenance manpower estimates should be interpreted with caution if, for instance, equipment is to be maintained in isolated geographic locations and there is no intention to keep permanent maintenance staff at these locations.

Model Maintenance and Use Costs

CASA is a microcomputer based model that runs on an IBM PC/XT/AT, PS/2 or compatible computer running DOS 2.0 or higher and having at least 640K of RAM.

DSMC are the proponents and maintainers of the CASA model. The College distributes CASA software free of charge to government agencies.

Contractors are used in the preparation LCC estimates using the CASA model. For example, the ASD Training SPO uses CLS for its simulators and the majority of these contractors use CASA to estimate LCCs and provide input to LSAs.

Model Strengths

Versatility and Depth of Coverage. The principal advantage of the CASA model is its ability to provide comprehensive coverage of the life cycle of a weapon system or sub-system thereof. CASA is able to address three phases of an equipment's life cycle--RDT&E, acquisition and O&S. Furthermore, the range of features available on the model allow it to be used for a number of other types of analyses in addition to LCC. For example, the Monte Carlo simulation feature of the model allows it be used for risk and uncertainty analyses; the model's comprehensive "what if" capability allows it to be used for assessing cost driver sensitivity; warranty analyses and RLAs are also able to be undertaken using the model.

CASA also provides considerable depth of coverage in its cost category equations. For example, it is able to accommodate up to nine levels of indenture in the description of equipment hardware; component reliability growth and production learning curve effects are also able to be taken into consideration; MTBFs for specific components are able to be adjusted using a maintenance degradation factor if

additional failures such as maintenance induced failures, sympathetic failures or other types of failures are significant; calculations of equipment repair cycle times take into consideration relevant factors such as "retest OK" (RTOK) investigation times; and the cost estimates output by the model can be inflated and/or discounted.

Monte Carlo Simulation Capability. CASA also has a unique risk assessment feature (at least unique amongst the models reviewed by the author). Although the main LCC model is deterministic in nature and uses discrete values in its cost calculations, the model also has a risk assessment module that allows an estimator "to quantify and measure the impact of uncertainty on the key parameters of the LCC Model --Unit Cost, MTBF, and MTTR" (53:Annex B,89). The user is able to choose from four probability distributions--Normal, Triangular, Uniform and Constant, to represent imprecision in these parameters and visualize the effect of uncertainty on the system LCC (53:Annex B,89).

Model Input/Output Capabilities. CASA had by far the most streamline and "user friendly" input/output capabilities of the LCC models investigated by the author. The model permits the rapid entry of a large amount of data in a logical fashion through a series of menu driven input screens. Additionally, the model's sensitivity analysis feature allows quick on-line cost comparisons to be made after a significant number of input parameters have been

changed. Also, the results of up the 10 LCC runs can be summed to provide an aggregate cost estimate for a large project. Moreover, CASA output is presented in a clear and readable format with clearly defined cost categories. The model also allows the user to add comments to output listings as an aid to readability or for insertion of decision notes (53:Sec 3,23; 53:Sec 6,31).

User's Manual. The user's manual for Version 2.01 of the CASA model was the best manual of the models reviewed by the author. The manual is well structured and clearly explained, and presents its information in a fashion that can be easily understood by the novice user without burdening an expert. The section on running the program, section six, is particularly good in the way it introduces the various program options and explains why each option is available and how it can be used.

Decisionmaker Confidence in Model. The CASA model has gained increasing acceptance since it was first introduced in 1986. Although the model has not been formally validated in the manner of the LSC model, several comparative studies have been undertaken using the original version of the model. For example, Minnick compared CASA against a modified version of the LSC model using a common data set in a 1988 study (126). The total LCCs calculated by the two models differed by 13.4 percent (126:333). Minnick explained the variation in results in terms of the different assumptions made by the two

models in relation to aircraft flying hours and various O&S costs, and concluded that both models produced reasonable results (126:335). Minnick believed that CASA was more robust than the modified version of the LSC model because of its ability to handle a greater number of LRUs/SRUs and support equipment and address a longer life cycle. Huth reports on a similar study comparing the outputs of CASA and the LSC model that was done by a USAF simulator contractor (105:31). In this study, a four percent cost difference was found between the two models after using identical input data (105:31). At about the same time, ASD/ALT compared the cost estimating capabilities of CASA against the LCCH model (89:1). ASD found comparable results between the two models in all cost categories except pipeline spares where there was initially a 68% difference (89:5). On closer examination of the discrepancy, however, they found that the LCCH model did not take into account the cost of repair parts and materials used at the intermediate maintenance level. When this cost was withdrawn from the CASA estimate, to maintain consistency in cost coverage, the overall difference in spares costs estimated by the two models was reduced to two percent (89:7).

The CASA model is currently being used by the Army, Navy, Air Force and USMC. The USMC is particularly committed to the model. The USMC recently estimated that on minor projects ($20-30 million) the depth of analysis permitted by

CASA is saving them in the vicinity of $2-$3 million per project (125:Annex E,1)

<u>Model Improvement and Validation</u>

CASA has undergone one major revision since it was first developed in 1986. This revision changed the host language of the model from Fortran to C, provided it with a much friendlier user interface, expanded the number of hardware items (LRUs) able to be handled by the model, added an additional LCC phase (RDT&E), enhanced the model's sensitivity analysis capabilities and added a comparison/ summation option to allow larger size projects to be analyzed. In total, these changes represented a significant improvement to the model. As far as expanding the basic usefulness of the model, the increase in the number of LRUs able to be modelled and the comparison/summation option were perhaps the most significant additions. The limited size of the original CASA model had meant that the model was only practically useful on smaller projects ($20-$30m) (125:4). The summation option allows bigger projects to be broken into segments for analysis by CASA and the results aggregated on completion of the individual runs. Up to ten separate runs can now be totaled in this way. Consequently, much larger LCC analyses can now be handled efficiently using CASA. Version 2.1 of the model will be released in the near future. The revision incorporates relatively minor changes in the model with enhancements in the application of inflationary

factors and the ability to spread RDT&E costs over a number of program years.

As mentioned previously, the CASA model has not been formally validated, although several comparative studies have been done (89; 105; 126). However, discussion with DSMC, the model's proponent, revealed that they intend to employ a consultant in the near future to conduct a detailed validation study on the model. The date for commencement of the project and the scope of the effort has yet to be determined (91).

The PRICE Models

Introduction

This section looks at the General Electric (GE) Parametric Review of Information for Costing and Evaluation (PRICE) family of models. There are six models in the PRICE group. The models and their primary functions are summarized below:

1. PRICE H--used for estimating hardware development and/or production costs.

2. PRICE HL--estimates the cost of supporting hardware during its operational life cycle.

3. PRICE M--used to estimate the cost for development and production of individual custom microcircuit chips.

4. PRICE S--estimates the cost for the design, implementation, test and integration of computer software;

the model also has a software sizing module (formerly PRICE SZ) and a module for estimating the operational support costs of a developed software system (formerly PRICE SL).

5. PRICE A--an activity analysis program that summarizes and calendarizes the resources needed to carry out scheduled projects and activities.

6. PRICE D--a statistical program used for performing regression analyses.

This section provides a description of the first four models detailed above, with particular emphasis on the PRICE hardware models (PRICE H, PRICE HL and PRICE M). Owing to the fact that the GE PRICE models are proprietary in nature, the author was unable to gain access to the model databases or investigate the logic of the algorithms or equations used in the models, except for information provided in user reference manuals. Consequently, this review is more descriptive than analytical in nature. The information presented in this section was derived from recent GE PRICE literature, model user and reference manuals, and from discussions with ASD cost analysts who operate the PRICE models.

Background of the Models

The first PRICE model, PRICE H, was developed by and for RCA in the early 1960s. GE literature indicates that the model "was first used rigorously in the mid to late 1960s and

early 1970s, especially to estimate avionics and space system costs" (81:Sec 2,1). During this period PRICE studies were undertaken for the USAF, USN and NASA. In 1975, RCA began to operate PRICE Systems as a commercial business unit, using the hardware model. In 1976, the hardware life cycle cost model (PRICE HL) was developed and a year later the software model (PRICE S) was added. The next major addition by RCA to the family of models was the development of the software lifecycle model (PRICE SL) in 1980. Then, in 1982, the microcircuit model was completed and made commercially available. The company changed hands in 1985 when RCA was taken over by GE. Shortly after, the software sizing model (PRICE SZ) was released. In 1988, GE released a revised version of the software model which, amongst other things, amalgamated the capabilities of PRICE SL and PRICE SZ into the new PRICE S model. Major revisions of PRICE H and PRICE M were also completed about the same time (132).

The PRICE models are updated by GE on a regular basis with new information added to model databases as it becomes available. The local GE PRICE representative advised that a major upgrade of the models is planned for late in 1991 but he was not prepared to elaborate on the changes (132).

Purpose of the Models

PRICE H. The PRICE H reference manual indicates that the model "is a computerized method for deriving cost

estimates of electronic and mechanical hardware assemblies and systems" (83:Sec 1,2). PRICE H is capable of estimating all aspects of hardware acquisition from the development and production of new systems through to the modification of existing equipment (83:Sec 1,3). PRICE H estimates the costs associated with design, drafting, project management, documentation, sustaining engineering, special tooling and test equipment, as well as material, labor, and overhead. The costs associated with integrating subassemblies into a system and subsequently testing the system for required operation are also considered by the model (83:Sec 1,3). However, PRICE H does not estimate the costs associated with field testing, site construction or software (83:Sec 1,3).

<u>PRICE HL</u>. The hardware related LCCs of electro-mechanical or purely mechanical systems are able to be evaluated using PRICE HL (84:Sec 2,1). Through its ability to interface with PRICE H, the model is able to draw in hardware parameters on a variety of different equipments and produce maintenance and support estimates (84:Sec 2,1). Additionally, PRICE HL is capable of "standalone" operation using user defined inputs. The model is able to tailor analyses to accommodate a wide variety of supply arrangements and maintenance concepts and thus fit the requirements of specific programs and user organizations (84:Sec 2,1).

<u>PRICE M.</u> The PRICE M model (Electronic Module and Microcircuit Model) was designed:

> to provide quick and reliable development and production cost and schedule estimates for electronic modules, printed circuit boards, hybrids and custom or standard microcircuit chips. (85:Sec 1,1)

Output from PRICE M may also be used to feed the PRICE H model in order to estimate the cost of complicated electro-mechanical systems and assemblies (86:Sec 1,4).

PRICE S. PRICE S has two modes of operation--acquisition mode and life cycle mode. The acquisition mode was designed "to estimate cost and schedule for both commercial and government software development efforts" (86:Sec 1,3,14). In life cycle mode PRICE S estimates the operation and support costs associated with software development (86:Sec 1,14). The two modes have beed designed to be used in conjunction with one another. The acquisition mode provides design parameters and development costs to the life cycle mode to supplement existing information describing the support activities and the support period (86:Sec 1,14). Alternatively, the life cycle mode of PRICE S may be used by itself to generate O&S costs (86:Sec 1,15).

General Characteristics of the Models

Common Themes. All four of the PRICE models described above are based on the same operating methodology. The key ingredients of this methodology are:

1. A parametric approach derived from statistical analysis of actual cost data.

2. Efficient modelling using a small set of easily comprehended input parameters.

3. Internal self-checking to test the consistency of input data.

4. Customizing flexibility so that...model[s] may be adapted to local definitions and accounting procedures.

5. Performance calibration, that relates current estimates to actual achievements on prior projects. (85:Sec 1,1)

<u>Model Access.</u> GE PRICE Systems, the managers of the PRICE family of models, make the models available via a computer time-sharing system accessible from user PCs or terminals over standard telephone lines (132).

<u>PRICE H.</u> PRICE H is actually a conglomerate of cost estimating and evaluation models and auxiliary programs. The user's reference manual for PRICE H indicates that in addition to estimating the costs associated with developing, producing, modifying, integrating and testing hardware, the model also includes methods for (83:Sec 1,7,8):

1. Calculating design and production "complexity factors" from user provided cost information.

2. Estimating multiple lot production costs.

3. Calculating the costs associated with integrating government furnished and commercially purchased equipment into designs.

4. Calculating hardware/software integration (HSI) costs.

5. Calculating the manufacturing complexities of nonhomogeneous assemblies.

6. Achieving any desired distribution of project expenditures.

7. Calculating field reliability.

8. Measuring the cost effectiveness of a reliability upgrade.

9. Expertly deriving the value of input parameters.

The basic data used by PRICE H to generate these outputs includes:

1. Quantities of equipment to be developed, produced, modified, purchased, furnished and/or integrated and tested.

2. Schedules for development, production, procurement, modification, integration and testing, including lead time for set-up, parts procurement, and redesign.

3. Hardware geometry consisting of size, weight of electronic and structural elements, and electronic packaging density.

4. Amount of new design required and complexity of the development engineering task.

5. Amount of repetition in hardware structural and electronic design.

6. Operational environment and specification requirements of the hardware.

7. Type and manufacturing complexity of the structural/mechanical and electronic portions of the hardware.

8. Fabrication process to be used for production.

9. Pertinent escalation rates and mark-ups for General and Administrative charges, profit, IR&D, cost of money, and purchased item handling.

10. Technological improvement.

11. Yield considerations for hardware development. (81:Sec 2,2)

Although PRICE H contains thousands of mathematical equations relating the input variables to cost, it is essentially a "cost-per-pound" model (87:33). Its generality is based on a scheme for classifying and projecting the cost of assemblies as a function of their electronic and structural weights and the complexity of the manufacturing processes involved. The model uses two manufacturing indexes--one for the structural or mechanical portion of the item (MCPLXS) and the other for the electronic portion of the assembly (MCPLXE). MCPLXS is a measure of the level of technology used in the assembly, its producibility (material, tolerance, machining difficulty), its operating platform and the labor required to build the structural part of the item. MCPLXE relates similarly to the electronic section of the item (82:Sec 2,8-10). The user can input the values for the manufacturing complexity indices, if he is familiar with the component, using standard value tables provided by GE PRICE or the model will derive values based on physical and electronic properties of the item input by the user. Alternatively, values for MCPLXS and MCPLXE can be derived from actual cost data for completed programs using PRICE H's Product Calibration Mode (83:Sec 3,55). In this mode, the output is not cost, but the manufacturing complexity that matches the cost and other input parameters (81:Sec 2,4). The PRICE H User's Reference Manual indicates that the calibration process "helps the user to establish

model references that are based on [actual] performance in producing or developing products" (83:Sec 3,55). In fact, calibration or "fine tuning" is critical to the adaption of the model to new products and new environments. GE PRICE Systems notes that:

> Once a user has performed this process on a number of case histories, a discernable pattern usually emerges with respect to the manufacturing complexities. This pattern is then refined and tested on other programs to yield the accounting and product calibrations that properly adapts PRICE to the new situation. (81:Sec 2,4)

The length of time required to adapt the model depends on the integrity of the cost data used for adaption rather than the number of programs on which cost histories are available (81:Sec 2,4). It is a true case of quality being superior to quantity. It is imperative, therefore, that the user validate the data used for calibration. GE PRICE believes that although this is a tedious task, the user's perseverance will ultimately save time. PRICE Systems also suggests that with "valid data and a concentrated effort to calibrate PRICE H, the adaption period should last no more than one month" (81:Sec 2,5).

PRICE HL. PRICE Systems literature indicates that the PRICE HL model is able to output seven categories of life cycle cost in each of three phases--development, production, and support, after input of a minimal number of program descriptors. The seven cost categories are (84:Sec 2,2):

1. equipment,

2. support equipment,

3. supply,

4. supply administration,

5. manpower,

6. contractor support, and

7. other (e.g., programming and documenting test equipment).

In addition to the above LCC information, the model also outputs an operational availability and operational readiness estimate. It also ranks, in order of cost, up to 28 preset or user defined maintenance concepts examined by the model (84:Sec 2,7).

In order to obtain this output information from PRICE HL, input data is required in three principal categories. These are (84:Sec 2,4):

1. Deployment and employment data--this information includes the number of deployment locations for equipment, equipment operating time, and number of maintenance and supply facilities.

2. Hardware parameters--these variables may be input from PRICE H or generated by the user.

3. Program global variables--these variables describe the available maintenance and supply organizations and the cost factors pertaining to these activities.

The user need only input data in the first two categories--

deployment and employment, and hardware; the model will use default values for the global variables (84:Sec 2,5).

PRICE M. The PRICE M model is able to prepare detailed cost estimates for all types of custom and standard microcircuits and electronic modules, and has the ability to integrate these results with estimates for assemblies developed using PRICE H to produce an integrated cost estimate for complex electro-mechanical devices (85:Sec 1,5).

The model requires inputs to describe the physical attributes of microcircuit chips or modules and detail the scope of the work involved. Other input parameters are used to inform the model of economic and schedule conditions. Additionally, certain input parameters may be calibrated to a specific organization or manufacturing facility, thus enabling the user to tailor the model to specific conditions (85:Sec 1,1).

PRICE M has several modes that can be used to prepare an estimate. The choice of operating mode is made automatically by the model on the basis of information provided by the user (85:Sec 1,2). The various modes are as follows:

1. Microcircuit mode--"emulates the procedures and processes involved in the design and fabrication of microcircuits" (85:Sec 1,2).

2. Module mode--uses a computerized modeling technique to produce cost and schedule estimates for the "design and

production of electronic circuit modules, boards or hybrids" (85:Sec 1,3).

3. Database Mode--allows common components that are used on many modules to be identified and grouped into files. The database files identifying the components can then be called as input during a module mode run to speed up the estimating process (85:Sec 1,3).

PRICE S. PRICE Systems' literature indicates that PRICE S can be used to obtain "rapid and early" probable software cost evaluations based on the scope and composition of a development project, processor loading and demonstrated organizational performance. The model also incorporates operational testing requirements as well as technological growth and inflation indices in order to obtain "realistic values for six cost categories in each of nine development phases (86:Sec 1,1). The nine phases align with the software development breakdown structure specified in DOD Standard 2167 but can be modified to accommodate commercially developed software (86:Sec 1,3). The six cost categories are (86:Sec 1,1):

1. design,
2. programming,
3. data,
4. system engineering/program management,
5. quality assurance, and
6. configuration management.

PRICE S also estimates typical schedules for development work in addition to cost (86:Sec 1,1). The underlying principle of PRICE S is that "all estimates involve comparative evaluation of new requirements in light of analogous histories" (86:Sec 1,2). The model will also perform sensitivity analyses which depict the effects of uncertainties in project descriptors and the development schedule (86:Sec 1,4).

PRICE S also has a calibration mode, very similar to PRICE H, which can be used to calculate empirical factors from completed program data. This tool allows the cost analyst to describe actual software experiences quantitatively, thereby permitting extrapolation to new software development projects (86:Sec 1,8).

PRICE S model inputs may be grouped into seven categories as follows (86:Sec 1,8):

1. Project magnitude--the number of lines of code.
2. Program application--the type of project.
3. Level of new design and code--how much new work is involved.
4. Productivity--relates to the experience and skill of the people who will do the work.
5. Utilization--relates to system hardware constraints.
6. Customer specifications and reliability requirements.

7. Development environment--what complicating factors exist.

The PRICE S model also has a life cycle cost mode which permits an estimation of the O&S costs associated with software development. The model separates support costs into three categories (86:Sec 1,14):

1. maintenance,
2. enhancement, and
3. growth.

Air Force Applications of the Models

The principal use of PRICE made by the Air Force is in verifying the reasonableness or otherwise of cost estimates submitted by contractors and sub-contractors during proposal evaluation and source selection. The USAF facilitates this process by requiring, in Request for Proposal (RFP) and other estimate submission documentation, that contractors model production and other relevant acquisition phase costs using the PRICE models and submit input and output files for various WBS elements for Air Force scrutiny. Air Force cost analysts then examine the hardware and software information provided, and attempt to reconcile material quantities and manufacturing complexities against contractor estimates (2).

A second use of PRICE made by SPOs is in preparing annual project budget estimates. Additionally, SPO acquisition milestone estimates are prepared using PRICE, as

well as ICAs. For example, the Milestone III estimate for the C-17 avionics suite was prepared using PRICE H, and the Advanced Tactical Fighter (ATF) Milestone II ICA for system software was done using PRICE S (2).

Model Assumptions

The basic assumption of the PRICE models and, for that matter, any parametric cost model is that past cost data can be used to project future costs. This assumption is generally sound when estimates are being made within the range of available data, but is fraught with danger when extrapolating beyond these limits, no matter how well a model has been calibrated.

Model Data Sources

The main sources of data used in operating the PRICE models are system contractors. As mentioned earlier when discussing applications of the models, a considerable amount of information is requested from contractors at RFP time and other estimate update occasions. This da[illegible] is then internally validated by Air Force cost analysts, in conjunction with system engineers, by examining system/ sub-system/LRU/SRU specifications and comparing these with known system weights, manufacturing complexities and costs. The revised information is then re-run through the models and compared to the original contractor estimate for reasonableness (2). For hardware items, PRICE Systems

provides tables of standard manufacturing complexity factors for various components, which can be compared against contractor generated values for similar items.

Potential Shortcomings of the Models

Proprietary Nature of Models. The proprietary nature of the PRICE models prevents analysts from examining model databases and estimating equations, and makes them susceptible to "black box syndrome". This occurs when analysts simply "plug-in" data and accept the generated output at face value without considering how the information was derived or whether the answer is reasonable. Consequently, there is a danger that non-sensical estimates will be prepared (2).

Adaptability of Models to New Technology. PRICE systems claims that estimating the costs of new system technology is one of the strengths of the PRICE models. Notwithstanding the fact that the models can be calibrated, there are inherent risks involved in using any parametric system that estimates costs by extrapolating beyond the bounds of existing data. Analysts must be aware of this risk in formulating estimates for futuristic systems.

Calibration Procedures. PRICE model calibration relies explicitly on the validity/integrity of actual data used in the process. In a number of Air Force situations, because of collection methods, the validity of data cannot be

guaranteed. Corrupt data has the potential to undermine the usefulness of the PRICE models calibration feature.

Expert System Preprocessors. Both the PRICE H and PRICE S models have expert system (XPERT) preprocessors that allow model users to create, edit and store all input data necessary to run the models. The ease of use and convenience of these expert systems encourages analysts to be lazy in preparing input data. However, use of the preprocessors is an expensive way to input data because it is treated as "log-on" time under PRICE time-sharing arrangements. In a number of cases, to overcome this data input problem, analysts have built data entry templates using spreadsheets that have ASCII file generating capabilities. The input data is stored in such a file and then downloaded to the PRICE model. In this manner, processing of a typical data file takes only 10 to 20 seconds log-on time, as opposed to many minutes using XPERT (2).

Strengths of the Models

Design Tradeoff Capabilities. The parametric nature of the PRICE models allows them to be used for design tradeoff studies during the conceptual planning stage of projects, when scant information is available on systems but the majority of subsequent LCCs are determined. The models are particularly useful because they are able to relate design parameters, such as component weight, material and

manufacturing/development complexity to cost, as well as system R&M characteristics.

Model Interrelationships. The fact that the PRICE models are able to interact and "feed" information to one another makes them a strong suite of models. Their ability to interact allows detailed estimates to be prepared logically and sequentially in an expeditious manner, without the need to duplicate inputs. Additionally, their interaction allows system estimates to be developed in progressively greater detail, as more information becomes available, and permits comprehensive coverage of the software and hardware components of a weapon system.

Model Support. All PRICE model users interviewed by the author agreed that PRICE Systems offered very good support for their models. Users indicated that advice was readily provided by the local support office, queries were quickly resolved, and system faults remedied in a timely manner. PRICE Systems also offers comprehensive training in the use of its models, which includes background information on the statistical bases of the models, as well as operating instruction.

Model Maintenance and Use Costs

As mentioned earlier, the PRICE models are accessed via a time-share system. Under current contract arrangements, the Air Force pays $82.00 per hour for operating time on the

system (2). ASD/FMC estimates that a "typical" annual estimate on a weapon sub-system, such as an avionics suite, takes 10 hours of "log-on" time to prepare. In addition to this, however, analysts must spend between 50 and 60 hours gathering and validating input data (even longer if a trip to the contractor's premises is required to gather particular information). The grade of analysts usually undertaking these estimates is between GS-7 and GS-13 (or military equivalent). In contrast, a milestone estimate for a major project, like the ATF can take approximately two months and involve a whole group of analysts (2).

Model Improvement and Validation

The PRICE models are being continually updated and improved by PRICE Systems. Model databases are updated as information becomes available on new hardware items. Periodically, changes are also made to improve the user friendliness of the models. The last significant changes were made in 1988 when expert system input preprocessors were added to the PRICE H and PRICE S models and the PRICECOM communication package was set-up to allow the user to go "on-line" and process data directly from a PC (82:Sec 5,3). The next significant revision of the models, planned for completion in late 1991, will involve a change in the models' host language from Fortran to C (132). However, PRICE

Systems was reluctant to discuss other features of the upgrade.

The Air Force has also asked PRICE Systems to consider moving away from time-share systems in its evolutionary development of the models. The USAF would prefer a "stand-alone" PC version of the model. It will be interesting to see how PRICE Systems reacts to this request.

In relation to model validation, PRICE models have not been validated in the same sense as the LSC model. However, the parametric nature and longevity of the models has helped them achieve a preeminent position among Air Force cost models and, consequently, they have obtained a type of "face" validity. Estimates prepared using PRICE models are accepted by the Air Force and OSD CAIGs. Additionally, feedback PRICE Systems has received from users of the models in private industry indicates that their estimates are, on average, reasonably accurate (132). Moreover, the models are able to be calibrated, which could be seen as a form of self validation.

The MLCC Model

Introduction

This section provides a brief overview of the Modular Life Cycle Cost (MLCC) model, a parametric based advanced aircraft engineering cost model. The information presented in this section is a synthesis of details contained in

several research papers which have examined the MLCC model, and a summary of discussions with the model's proponent, the Wright Laboratories, Plans and Programming Directorate (WL/XPA). A more detailed examination of the model was not possible because of security restrictions which prevented the author from gaining access to the model's manuals and databases.

Notwithstanding this, the model is reviewed because of the significance of its aims. MLCC is unique in that it was specifically designed to assist design engineers in conducting performance/design/cost tradeoff studies during the concept analysis and preliminary design stages of a weapon system's life cycle (65:7). Johnson notes that early consideration of LCCs is crucial in the development of a new weapon system because 70 to 80 percent of subsequent system costs are "locked-in" during the design phase (109:8).

Background of the Model

The program for the MLCC model was developed by Grumman for the Air Force Flight Dynamics Laboratory at Wright-Patterson AFB in the late 1970s. The Flight Dynamics Laboratory sponsored the project because they needed a model that would allow them to cost developmental aircraft 15 years or more into the future. Moreover, they saw fundamental weaknesses in existing aircraft cost estimating models. Most of the models available at the time used aircraft weight as

the main cost driving element (116). Johnson notes that there had been an overreliance on gross weight in "past cost-estimating methods" (109:26). She suggests that while weight is important when considering "conventional materials and structural methods", recent advances in material and manufacturing technology have allowed the development of "exotic" materials that have increased structural efficiency and reduced weight. As a consequence, she adds, cost and weight nolonger, necessarily, bear a direct, positive relationship to one another and, therefore, estimates based solely on gross weight predictions may not accurately predict costs (109:27). The MLCC model provided a significant improvement over existing models by allowing the aircraft designer to consider the cost impact of other design parameters such as volume, density, fuselage wetted area, length and wing span (109:127; 65:7).

Grumman's development of the model was a long term effort, undertaken in successive phases between 1976 and 1986. The majority of this time was spent compiling an extensive data base of aircraft design, performance and cost data, and progressively updating it. The model's CERs were then derived using this data base. Grumman developed two separate data bases, one for the airframe and associated subsystems, and the other for engine information. Next, two separate sets of CERs were derived, one for cargo/tanker/transport type aircraft and the other for fighter/attack type

aircraft. The first usable version of the model was produced in 1980 (148).

During the next stage of the model's development, the database was updated to include the latest design parameter and cost information on those aircraft already described in the database. Following this, data on new aircraft, most significantly bombers (which had not been included previously), such as the B-52G and FB-111A, were added to make the model's coverage more comprehensive. New LCC CERs were then developed and integrated into the Master Control Program (MCP) and cost data was also normalized to a 1980 base year. Additionally, as part of the revision effort, the cost factors used to describe advanced metallic and composite material production costs were updated and refined to reflect state-of-the-art technology for the 1990-1995 timeframe (148). This phase of the work was completed in 1985.

The last stage of the project was finally completed in 1986 when corrosion and R&M sensitivity analysis modules were incorporated into the model to enhance its utility (148).

The Flight Dynamics Laboratory has made only one change to the model since that time. Grumman wrote the MLCC model program in FORTRAN IV and designed it to run on a CYBER minicomputer. In 1986, Flight Dynamics Laboratory personnel converted the model to FORTRAN 77 and rehosted it on a MicroVAX III machine. The principal aim of this effort was to increase the portability of the model (148).

In 1990, Mr John Phillips of Lockheed developed a PC version of the MLCC model using a Lotus 1-2-3 spreadsheet. AL/XPA advise that the PC version of the MLCC model is significantly more user friendly than its minicomputer counterpart (148).

Purpose and Uses of the Model

The MLCC model was developed to allow aircraft LCC tradeoff studies to be conducted, at the subsystem level, during the conceptual and preliminary design phases of a new aircraft development program (148). The methodology of the program allows the design engineer to relate cost to system design parameters, thus enabling him to cost his design at a stage when design changes can easily be accommodated without a significant impact on the program (148). The model's consideration of O&S costs also allows "visibility" of these important cost elements during the early stages of a program before they become "locked-in" (148).

The MLCC model is currently being used by WL/XPA in a study looking at a future multi-role fighter for the Air Force (148).

General Characteristics of Model

The MLCC model operates on the basis that a system's LCC is the sum of the following costs:

1. research, development, test and evaluation (RDT&E),
2. production costs,

3. support investment costs, and

4. O&S costs.

The only unusual category in the description is support investment. These costs include outlays for support equipment, training and initial spares, and also customer preferred options and equipment, such as external fuel tanks and pylons, and racks for munitions (148).

The above costs are analyzed across 12 aircraft subsystems. These are (148):

1. airframe,
2. crew systems,
3. landing gear,
4. flight controls,
5. cargo handling (cargo aircraft only),
6. engines,
7. engine installation,
8. environmental control system,
9. electrical,
10. hydraulic/pneumatic,
11. fuel systems,
12. avionics,
13. armament (fighter/attack/bomber aircraft only),
14. auxiliary power unit (cargo/transport/tanker aircraft only).

This structure allows the design engineer to see what portions of the aircraft are the major cost drivers.

Over 100 input parameters are used in the model's CERs in order to calculate the LCC of a system. These variables range from the thrust to weight ratio of the engines, the number of tail surfaces and weight of avionics, through to production and labor rates, inflation factors and the slope of production learning curves. The input variables can be roughly categorized into three groups--design parameters, performance landmarks and economic factors. The data is entered into the model in batch mode (148).

Model Data Sources

The input data used to plug into the model's CERs is obtained from available aircraft sizing models or from conceptual/preliminary design data derived by the design engineer (148).

Model Strengths and Weaknesses

Strengths. The main strength of the MLCC model, as mentioned previously, is its ability to allow cost to be considered in design tradeoff studies during the concept development and preliminary design phases of a weapon system. Another one of the model's more desirable features is its ability to determine the costs associated with applying seven advanced materials to the wing, fuselage, tail and nacelle areas of an aircraft (148). The model does this through the use of a materials index. Aluminum is used as the baseline for the index (110:31-32).

Weaknesses. The principal strength of the MLCC model, its ability to be used during the development/preliminary design phases of system's development, is closely associated with its parametric nature. However, it is the model's parametric nature that also accounts for its major weakness. Daniel notes that advances in technology threaten to provide the "revolutionary discontinuity" that will ruin parametric extrapolation. He also suggests that the ever lengthening period between major new weapon systems projects causes an erosion of the database used to derive CERs (32:7).

In light of the above, Johnson believes that it is particularly important that cost analysts and design engineers understand the origin and composition of a model's database, and be aware of the limitations of CERs (109:29). Understanding the origins and composition of the databases is particularly difficult in the case of the MLCC model owing to the fact that its databases were never automated by Grumman or documented beyond the delivered technical reports. As a result, the proponents of the model, WL/XPA have found it virtually impossible to trace the sources of data or keep the model's databases up-to-date. Staley suggests the MLCC databases, and therefore the model's CERs, are seriously in danger of becoming obsolete unless a concerted effort is made update them in the near future (148).

Another area of concern is the user "crankiness" of the minicomputer version of the model. WL/XPA advise that the

model requires that data be input as an ASCII file. The program used by the MLCC model to translate the ASCII data for input to the model is extremely sensitive to the placement and format of data, e.g., numbers must be entered in exponential form. Additionally, if a fatal error occurs during compilation, because of a data format problem, the program does not provide any type of error message to highlight the cause of the failure to the analyst. Consequently, a considerable amount of time must be spent "debugging" computer runs. Furthermore, the model also increases the chance of input errors and data inconsistencies by requiring that data common to a number of aircraft subsystems be entered repetitively (148).

Model Maintenance and Use Costs

The MLCC model was developed and maintained for the Air Force, between 1976 and 1986, by Grumman. Since then the model has been managed by WL/XPA. At present, only one person, Mr Greg Staley, is operating and maintaining the model at WL/XPA on behalf of the other WL laboratories. Computer operating expenses are minimal now that the model has been converted for use on a PC.

Model Improvement and Validation

As mentioned previously, development of the MLCC model was managed as a phased project by Grumman, between 1976 and 1986, with each stage adding additional features and depth to

the model's area of coverage. For instance, the original databases developed by Grumman during the period 1976 to 1980 did not include any data on Air Force bombers (110:88). This reduced the predictive power of the model in this area. The deficiency was rectified as part of the database upgrade conducted over the period 1982 to 1985. The next major upgrade was completed in 1986 when aircraft corrosion sensitivity analysis and subsystem level R&M cost prediction enhancements were added to the model.

Additionally, since the conclusion of Grumman's involvement with the model, WL has rewritten the minicomputer version of the program in FORTRAN 77. This was done in 1986 to increase the portability of the model. In 1990, a PC version of the MLCC model was developed by Mr John Phillips of Lockheed using a Lotus 1-2-3 spreadsheet (148). This version of the model is significantly more "user friendly" than the minicomputer edition programmed in FORTRAN 77, but WL/XPA has yet to verify the authenticity of the equations used by Phillips against the original FORTRAN code (148).

In relation to model validation, the author is aware of one study, conducted by Decamp and Johnson in 1982, which compared the estimating ability of the MLCC model against a parametric airframe model that was in widespread use at the time, the Development and Procurement Cost of Aircraft (DAPCA III) model. Using data on the F-15, F-16 and AV-8B, the study found that estimates from the two models were within

three percent of one another (34). WL/XPA has not been able to do a great deal in the model validation area because of funding and manning constraints. Notwithstanding this, it is extremely difficult to empirically validate a model that is being used during the concept exploration and preliminary design stages of a system that may not enter production for another 15 to 20 years. An alternative approach, which WL/XPA is pursuing, is to check the veracity of the cost, design and performance data contained in the Grumman developed databases and update it as necessary. However, data verification and validation is extremely time consuming when the exact source of the original data is unknown. Each day that the work is delayed, however, increases the risk of the databases becoming obsolete.

V. Specialized Models

Chapter Overview

This chapter describes two models which are generally not classified as LCC models. They are the Dynamic Multi-echelon Technique for Recoverable Item Control (Dyna-METRIC) model, and the Logistics Composite Model (LCOM), both of which were developed for the Air Force by Rand. The two models are included in this study, however, because of their potential to provide significant input to LCC analyses. For example, Dyna-METRIC will soon replace Mod-METRIC as the USAF's primary tool for calculating world-wide engine requirements. Additionally, when used in its requirements computation mode, the model also has the potential to supplement or replace spares equations in less sophisticated LCC models. LCOM is of interest because its manpower computations provide basic inputs to a number of LCC models including the CORE factor model.

The Dyna-METRIC Model

Background of the Model

The Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) is the current state-of-the-art capability assessment model used by the Air Force for relating aircraft reparable item supply levels and

maintenance capability to squadron wartime readiness. The background to the development of Dyna-METRIC can be viewed from two interrelated perspectives; one theoretical and the other political. Each of these perspectives will be examined in turn.

<u>Theoretical Perspective</u>. Dyna-METRIC's development was truly evolutionary. The roots of the model can be traced back to the Base Stockage Model developed by Sherbrooke at Rand in 1965 (142). This model was designed to minimize the expected number of backorders in a multi-item reparable inventory at an air base (single echelon), subject to a constraint on system investment (143). Sherbrooke employed the same mathematical approach, applying it to the more complex base-depot supply system, in developing the Multi-Echelon Technique for Recoverable Item Control (METRIC) model in 1966 (144). METRIC was designed for control of any reparable and was able to optimize stocks of these items at both base and depot echelons given a fixed budget constraint or backorder objective (143:123-124).

However, because METRIC did not distinguish between differently indentured reparables it tended to recommend the purchase of too many "cheap" SRUs and too few "expensive" LRUs. Accordingly, the next logical step in the development of the model was for explicit consideration to be given to the relationship between LRUs and SRUs in a multi-echelon

system. This evolutionary progression was completed by Muckstadt in 1973 in his development of Mod-METRIC (127). In addressing the multi-indenture issue, Muckstadt sought to overcome several problems inherent in METRIC. Firstly, METRIC assumed that backorders for different LRUs were equally undesirable. Muskstadt was able to demonstrate that component essentialities differed when both LRUs and SRUs were considered (127:475). Secondly, METRIC's failure to consider indentured relationships caused it to buy too many low cost items (16:21). The average resupply time calculated using the two models differs because Mod-METRIC takes into consideration the expected delay in base LRU repair owing to an SRU backorder at the base (127:476-477).

Both METRIC and Mod-METRIC assume a peacetime (steady state) operating environment in performing their calculations. Owing to the fact that the Vietnam War was still in progress, increasing interest began to be shown in dynamic (time-dependent) models. Christensen notes that in 1972 Gilbert and Faucett "developed nonsteady state solutions for poisson demand and resupply systems" (16:22). Shortly after, the first transient models began to appear. In 1978, Demmy broke new ground by modeling dynamic solutions for simple Poisson failure processes in a two-echelon supply system. Subsequently, using this research, Hillstadt and Carrillo were able to derive transient

equations and apply these to a number of time dependent measures of system performance, similar to what METRIC had done with backorders in the steady state situation (16:22). Notwithstanding this, steady state models remained in favor and attempts continued to adapt these models to dynamic conditions. However, in 1980, Muckstadt was able to demonstrate that steady state inventory models produced inaccurate estimates of stock requirements and supply system performance when applied to a dynamic environment (128).

Political Influences. At about the same time, political attention began to focus on the readiness issue. Congress became increasingly concerned that the DOD could not explicitly relate resource commitments to future readiness levels. In 1977, Charles W. Groover, Deputy Assistant Secretary of Defense (Program Integration) MRA&L explained the DOD's predicament in relation to the readiness issue as follows:

> We believe we have a pretty fair understanding of how the logistics system operates to support our combat weapon systems.... However, the specific functional relationships between resources applied and material readiness resulting is incredibly complicated. (90:7)

At the time, readiness reporting by the services consisted of rating the readiness of separate groups of resources necessary to support a combat unit, e.g., spares, munitions, fuel, aircraft, personnel. The resource with the lowest rating defined overall unit readiness (98:2).

Hillestad notes that the measures used for the different resources were not compatible and, accordingly, they did not reflect the overall ability of the organization to perform its combat mission (98:2). The 1980 DOD Material Readiness Report acknowledged the problem:

> The Department of Defense (DOD) spends billions each year to maintain the readiness of its weapon systems but cannot accurately project how much readiness a dollar will buy or determine how much readiness is needed....To date, DOD has made little progress in linking funding and material readiness and has not achieved an adequate material readiness report for the Congress. (79:23)

In response to this criticism, the Air Force established a major objective in its 1981 Logistics Long Range Planning Guide to "develop a means to better identify and assess logistics requirement and capability, especially as these relate to execution of U.S contingency plans" (98:2). The Air Force sought a technique for describing readiness that used consistent measures and considered interaction amongst resources. Dyna-METRIC appeared to be the answer.

Emergence of Dyna-METRIC. Dyna-METRIC was developed by Rand in the early 1980s to "study and predict the readiness of groups of aircraft squadrons as determined by a major subset of logistics resources...component repair and supply" (98:2). It attempted to overcome two of the problems mentioned above by combining the influence of several different types of support resources and measuring

their direct effect on mission readiness (98:2). Dyna-METRIC aimed to avoid the loss of aircraft mission capability caused by shortages of functioning components on the aircraft. This objective was similar to the aim of METRIC and Mod-METRIC, however, these models used expected number of backorders as a proxy measure of aircraft availability rather than directly addressing the availability issue. The key characteristic of Dyna-METRIC, however, was its ability:

> to deal directly with the transient [time dependent] demands placed on component repair and inventory support caused by dynamic parameters in a scenario (sortie rates, mission changes, phased arrival of component repair resources, interruption of transportation, etc). (98:4)

Dyna-METRIC portrays component support processes as a network of pipelines through which aircraft components flow as they are repaired or replaced (136:9). Specifically, it forecasts the quantity of each aircraft component in repair and resupply throughout an operational scenario, based on the component's unique interactions with developing operational demands, and combines these quantities probabilistically to estimate how all the aircraft components jointly might affect aircraft availability and combat sorties throughout the scenario (136:vii). Additionally, the model's analytical nature allows it to identify those problem parts that most limit aircraft

availability or, alternatively, suggest a cost-effective stock purchase to improve aircraft availability (136:vii).

Evolution of Dyna-METRIC

Dyna-METRIC 3.04. The first version of Dyna-METRIC released to the Air Force was Version 3.04 in August 1981 (6:13). This release combined capabilities that were available in previous versions of the model with others developed in a variety of special studies at Rand and in the Air Force (6:13). Version 3.04 was subsequently adopted as the "baseline" version for integration into the AFLC Weapon System Management Information System (WSMIS) to perform assessments of "planned and actual stock support to single aircraft mission design series in standard, single theater operation plans" (107:1).

Version 3.04 was able to model multiple bases and Centralized Intermediate Repair Facilities (CIRFs). It assumed, however, that each base was supported by only one CIRF. Repair at the depot level was not explicitly analyzed in the model. The influence of depots was negated by assuming that they had unlimited stock which was available after an order and ship time. The indenture structure was also specialized in that only two levels of indenture below the system level were allowed, i.e., LRUs and SRUs. The model's ability to handle LRUs and SRUs was limited only by available computer capacity. SRU availability was used to

compute an awaiting parts (AWP) pipeline for its parent LRU, and a part specific repair cycle time (RCT) was used to represent the repair process. Additionally, the model assumed that full cannibalization of parts was allowed.

Version 3.04 of the model also made a number of other assumptions. Firstly, it assumed that "ample" repair resources existed to achieve the user specified RCT. When appropriate data existed, the user could specify test equipment productivity constraints that Dyna-METRIC would use to estimate repair resource queues and their affect on wartime capability. However, in practice, this information was seldom available. Furthermore, the model assumed that aircraft comprised only those components specified in the model database, and component failures were directly proportional to flying activity (136:32). The model operated on the basis that any component failure would ground an aircraft, i.e, Dyna-METRIC did not account for varying component essentiality. Accordingly, in model scenarios, aircraft were either fully mission capable (FMC) or not fully mission capable (NFMC); no partially mission capable (PMC) aircraft were allowed (40:3-4). Additionally, the model assumed that aircraft at each base were nearly interchangeable, i.e, they are composed of essentially the same components (136:35-36). The Dyna-METRIC repair

process was also assumed to be characterized by a long diagnostic period followed by rapid repair (136:36-37).

Dyna-METRIC 4.4 On closer observation, it is readily apparent that some of the assumptions in Version 3.04 of the model are tenuous, particularly the ones relating to unconstrained repair resources and component essentiality. Version 4 of Dyna-METRIC was developed by RAND to address some of these limiting features and also better represent the wholesale (depot) system. More specifically, the version accommodated an additional echelon of component repair and supply--the depot-level, and an extra level of component indenture--sub-SRUs. The update also incorporated an ability to analyze multiple aircraft types, and included a substantial amount of extra detail in the description of the component pipelines. Additionally, the model's report capabilities were also enhanced (107:iii). The primary aim of the upgrade, however, was to allow the model to conduct "worldwide analyses of logistics support for aircraft components" (107:v).

Version 4.4 cf the redesigned model was released as a standard version in 1988 and was adopted by AFLC for use in the Sustainability Assessment Module (SAM) of WSMIS. Here, Dyna-METRIC is used to assess the capability of war readiness spares kits (WRSK) to sustain wartime aircraft operations given current levels of spares stocked (129).

Version 4.4 is still being used by AFLC, although Version 4.6 will be adopted before the end of June 1991. Version 4.6 is essentially the same as its predecessor, however, data input/output routines have been streamlined to improve the speed of the model and the latest edition also allows weapon systems other than aircraft to be modeled. Furthermore, the repair echelon structure has been expanded to allow the inclusion of a theater depot repair facility, similar to that used in Operation DESERT STORM (129).

PC Versions of Dyna-METRIC. Microcomputer versions of Dyna-METRIC have also been developed by the Air Force for use outside of AFLC. For instance, the Air Force Logistics Management Center (AFLMC) adapted Rand's Version 3.04 for use on a PC at major command (MAJCOM) bases to allow unit level assessment of WRSK/base level self-sufficiency (BLSS) kits. This version of the model became known as miniature Dyna-METRIC (MINDM). The model was developed to overcome the problem caused by the timelag in obtaining capability assessment information from AFLC at base level. Quite often, despite careful planning, there are a number of last minute changes that alter the concept of specific deployment or exercise plans. The number of aircraft involved changes, airlift capacity is altered, or the maintenance or resupply concept is rearranged (77:24). In these situations, prior to MINDM, the base was essentially left to "fend for itself"

and make educated guesses about what was needed to be changed in WRSK/BLSS kits. MINDM provided the means to rapidly assess the effect of WRSK/BLSS changes on squadron sortie generation capability. The scope of MINDM was later expanded, as part of the WSMIS development, to include a requirements determination capability in addition to its sustainability assessment module. The revised model became known as the Dyna-METRIC Micro-Computer Analysis System (DMAS) and is in widespread use throughout the Air Force today (129).

Continued Rand Development. Rand has also continued its development of Dyna-METRIC. Version 5 of the model was developed to overcome problems experienced by earlier versions in representing the uncertainties inherent in demand and repair, "especially the queuing caused by repair constraints, or the actions management might take to overcome unanticipated demands" (106:1). Version 5 also added more realism to the model by allowing lateral resupply and priority repair scheduling. However, in order to allow the "ample service" assumption to be dropped it was necessary to abandon Palm's analytical theorem and adopt Monte Carlo sampling as the basis for the model (106:1-2). The adoption of simulation methods caused a loss in model efficiency and necessitated the withdrawal of a number of Version 4 features. For instance, Version 5 did not

consider the indentured nature of LRUs. SRUs were assumed to be in plentiful supply so they never delayed the repair of an LRU. It was also necessary to limit problem parts diagnosis and omit spares requirements computations (106:8).

Subsequent versions of the model developed by Rand have retained Monte Carlo simulation and sought to improve the model's efficiency while, at the same time, reintroducing a number of features present in Version 4.4. The latest version of the model developed by Rand is Version 6.3 (129). However, the speed of the model is still not sufficient for it to be considered for implementation as a standard version, and, therefore, the Air Force continues to use an analytical version of the model.

Purpose of the Model

Dyna-METRIC was designed to be used by logisticians as a tool for forecasting squadron aircraft performance and diagnosing wartime logistics constraints (136:v). The model does this by (136:vi):

1. Providing operational performance measures that enable logisticians to see how repair and resupply processes combine to affect overall weapon system support.

2. Incorporating the effects of wartime dynamics, such as increased component demand, on the logistics system.

3. Identifying and ranking problem components that cause "excessive degradation of wartime capability, so

attention and efforts can be focused on improving support for the most serious problems" (136:vi).

4. Suggesting "a cost-effective mix of component spares to achieve a target wartime capability" (136:vi).

Current Uses of the Model

The principal use of the Dyna-METRIC model, as currently implemented in WSMIS and DMAS, is to assess the wartime capability of existing WRSK and BLSS kits (9:26). AFLC performs this operation on a weekly basis, using WSMIS, providing a squadron level combat capability rating for over 300 units worldwide. In addition, assessments of various theater level capabilities are undertaken quarterly. The list of "problem components" identified by Dyna-METRIC as part of these capability assessment runs are input to WSMIS's Get Well Assessment Module (GWAM) for follow-up action and monitoring; these items form the basis of the "Critical Item Program" (129). At the base-level, MAJCOM units use DMAS to assess their own capabilities based on the latest WRSK stocking information available.

In addition to capability assessments, by operating in "backwards" mode, Dyna-METRIC can also be used to compute wartime requirements. The model was used for this task for a brief period in 1988 in the WSMIS Requirements Execution Availability Logistics Module (REALM), but was replaced by the Logistics Management Institute (LMI) Aircraft

Sustainability Model (ASM). Dyna-METRIC was superseded by ASM in this role because while it accurately portrays an SRUs impact on an LRU from a weapon system availability viewpoint, it does not optimize the SRU/LRU tradeoff; that is, it does not consider the least cost mix of LRUs and SRUs needed to satisfy a weapon system availability goal (9:27).

However, Dyna-METRIC will replace Mod-METRIC, in the near future, for determining world wide aircraft engine requirements. Sub-optimality is not a concern in this case because engines are purchased separately from other aircraft systems and are provisioned to an 80 percent ready rate objective (129).

Model Data Sources

Dyna-METRIC requires detailed information in three major areas in order to operate. These areas are as follows (149:14-17):

1. Stock Levels and Logistics Performance. Actual quantities of spare parts "on hand" are required for each squadron tasked in the scenario under investigation. This information is obtained from the world-wide Combat Supplies Management System (CSMS). In addition, logistics information on component failure rates, base and depot repair times, order and ship times, and depot stockage levels is also required. This information is obtained from system managers and a number of AFLC data systems, including

D029 (WRSK Computation System) and D041 (Recoverable Consumption Item Requirements System) (129).

2. Operational Plans. In the operations area, information is required on the number of aircraft at each base, the number of sorties per day, and the average flight duration of each sortie. This data is obtained from the current War and Mobilization Plan (WMP-5).

3. Deployment Plans. Specific information on deployment plans, including projected force changes by base and changes in sortie requirements over time are obtained from the MAJCOMs.

Shortcomings of the Model

The major limitations of each version of Dyna-METRIC were discussed in detail in the section relating to model evolution. Accordingly, this section addresses the issue of model shortcomings in a more general sense as related to the currently implemented version of Dyna-METRIC, Version 4.4. As noted previously, Dyna-METRIC Version 4.4 is an analytical model based on Palm's theorem. Palm demonstrated that pipeline quantities take on a Poisson probability distribution with means that are the product of the items average failure rate and average repair time. Hillestad and Carrillo provided the basis for Dyna-METRIC in 1980 when they demonstrated that Palm's results could be extended to dynamic wartime situations (99). However, while Palm's

theorem facilitated the development of Dyna-METRIC, its theoretical limitations have also impeded the model's progress.

Palm's assumptions relating to ample maintenance service capacity and independence between the demand and supply process have proven particularly difficult for model developers to overcome. "Workaround" solutions have been tried. For example, Version 4.4 attempted to address the problem of no queuing delays for repair by using an expected value simulation. This method was able to capture the first order (mean) effects of expected repair demands and resource availability, but it did not account for the variance in demands. As a result, the expected queue size was underestimated (106:1-2). Isaacson and Boren note, however, that even if the queuing problem had been solved, "the assumption that component pipelines are independent would still have proven troublesome" (106:2). Priority repair, for instance, assumes that knowledge of one component's pipeline provides us with information about the size of other components' pipelines and attempts to level all the pipelines, introducing some degree of correlation. Isaacson and Boren suggest that by treating the true pipeline probability distributions as independent we underestimate the number of available aircraft (106:2).

Monte Carlo sampling was introduced in Version 5 of Dyna-METRIC in order to allow the ample server and independence assumptions to be relaxed (106:2). However, the new method slowed the operation of the model to such an extent that it could not be considered for practical implementation within the Air Force (129). Consequently, AFLC and the MAJCOMs continue to operate the analytical version of the model, reconciling their decision on the basis that not enough information is available to conclusively prove or disprove the repair capacity assumption (129).

Model Improvement and Validation

The validity of Dyna-METRIC's capability assessment estimates has been tested in five wartime scenario exercises. These were:

1. CORONET WARRIOR I (7 July to 6 August 1987),
2. CORONET WARRIOR II (10 May to 8 June 1988),
3. BULL RIDER (2 August to 3 September 1988),
4. VOLANT CAPE (22 August to 30 September 1988), and
5. CORONET WARRIOR III (17 April to 14 May 1989).

CORONET WARRIOR I involved the deployment of twenty four F-15s from the 94th TFS at Langley AFB (40); CORONET WARRIOR II involved twenty four F-16s from 17th TFS at Shaw AFB (76); seven B-52Gs operated under wartime conditions from Clinton-Sherman Air Park in BULL RIDER (41); sixteen

C-130Es were deployed to Little Rock as part of VOLANT CAPE (47); and thirty one A-10s took part in CORONET WARRIOR III at England AFB. The exercises were specifically designed to test the ability of depleted WRSKs to sustain wartime operations. The results obtained were then compared against Dyna-METRIC's predictions of squadron readiness and sustainability.

In each case, flying schedules were built to match the Dyna-METRIC scenario as closely as possible in order to test the realism of key model assumptions. "Ample" repair capacity was provided by having a sufficient number of people and equipment to accomplish daily flightline removals and replacements and intermediate maintenance tasks. No lateral or external resupply was allowed.

A number of common themes were evident in all four exercises. The first one relates to Dyna-METRIC's validity. In each case, when actual exercise demand data was "plugged" back into the model at the conclusion of the deployment, Dyna-METRIC's estimate of the number of FMC aircraft available on the last day of each exercise was very close to that actually experienced. However, using pre-exercise data, it was found that Dyna-METRIC tends to consistently underestimate the number of aircraft available. Therefore, the model provides a useful conservative estimate of squadron capability. In addition, the model also proved

useful for identifying the spares most likely to cause aircraft groundings. However, its estimate of the number of sorties generated each day was not very accurate. This is because Dyna-METRIC assumes a linear relationship between the number of FMC aircraft available and the number of sorties generated, whereas, in the real world the relationship is much more complex. In reality, flight-line resources such as fuel trucks and munitions loaders limit a base's ability to turn aircraft. Moreover, operational plans may require that available aircraft be used in ways that preclude efficient use of those flight-line resources, e.g., mass aircraft sorties (136:33-34).

The exercises also revealed that "human resourcefulness" can have a significant impact on operational capability. A considerable amount of synergy was generated during all the exercises by motivated flight crews, maintenance and supply personnel working together. Personnel innovated and improvised more and more as each exercise progressed and solved previously unsolvable problems (40; 76; 138). A closely related issue, worthy of further consideration, is the effect of operational "learning curves". In all the exercises, the aircraft break rate, as determined by dividing the number of aircraft that flew each day by those that landed with one or more code three write-ups, decreased over the duration of the

deployments. If component reliability can be assumed constant, a substantial proportion of the improvement in aircraft performance could, quite reasonably, be attributed to an increase in the standard of maintenance.

A problem that also became evident during the exercises is the apparent wide disparity between actual demands for certain WRSK items and predicted demands, as determined using D029. In other words, it appears that peacetime demand rates for a number of items are significantly different from wartime demand rates. This phenomenon has important implications for Dyna-METRIC and its ability to accurately portray squadron readiness. Owing to its sensitivity to demand rate changes, Dyna-METRIC has little hope of accurately predicting readiness levels if the scenario demand rate differs markedly from the input demand rate. The obvious conclusion is that more effort needs to be devoted to ensuring the validity and accuracy of data input to the model.

Conclusion

Dyna-METRIC has undergone a considerable amount of evolutionary change since it was first developed by Rand in the early 1980s. During the intervening ten years, it has been implemented by the Air Force in various formats and used for a number of different purposes at both command and unit levels. The model is now the Air Force's primary tool

for assessing the combat readiness and capability of USAF squadrons located in the U.S. and throughout the rest of the world. The validity of the model was recently tested in a number of wartime scenario exercises. Although these exercises revealed that further model refinements are required, they confirmed the basic validity and usefulness of Dyna-METRIC. Dyna-METRIC is now institutionalized within the Air Force and seems set to continue in its present role, or an expanded one, well into the foreseeable future.

The LCOM Model

Introduction

The Logistics Composite Model (LCOM) is a discrete event, Monte Carlo simulation model that is used by the Air Force as its primary analysis tool for establishing maintenance manpower requirements. Over 50 percent of the USAF's maintenance work force is justified or "earned" through LCOM simulation (18). Boyle notes that "LCOM simulation is connected by Air Force Regulation 25-7 to the manpower standards process, and through this to the Air Force budget" (11:1).

LCOM is not normally included in the category of LCC models. However, it has been classified as such, for the purposes of this analysis, because its maintenance manpower

requirements computations are frequently used as inputs in LCC studies. For example, the AFR 173-13 CORE model uses LCOM derived maintenance manpower figures in calculating annual squadron operating costs (18).

Background of the Model

Development of LCOM began in 1966 as a joint effort involving personnel from HQ AFLC and the Rand Corporation (74:iii). The model was originally developed to overcome a number of problems experienced in the analysis of the results of Project PACER SORT. The project, which was sponsored by AFLC, was designed to allow an evaluation of the ability of revised repair and maintenance procedures to provide support for tactical aircraft during both peacetime and contingency operations (74:2). The field test involved two squadrons of F-4C aircraft deployed, under combat conditions, in South Vietnam. The main objective of the exercise was to determine the most cost-effective mix of base and depot repair taking into consideration requirements for maintenance personnel, spare parts, support equipment and other resources. However, in the post exercise analysis it was found that the best mix of base and depot repair could not be determined because the nature of the data gathered made it impossible to evaluate repair policy gradations. Moreover, the test data had little applicability to other aircraft types operating in different environments. Simulation was seen as a means of replicating

the environment of the field test without incurring the expense of another deployment (74:3).

The completed LCOM model was implemented at HQ AFLC in 1967. However, AFLC felt that LCOM did not meet their specific needs and, following the PACER SORT simulations, they "shelved" the model (29). Then, in 1971, TAC became aware of the existence of LCOM and requested a copy. TAC began using the model for determining the maintenance manning requirements of current weapon systems. TAC found that LCOM simulations allowed wartime manpower standards to be evaluated in a manner not previously possible (60:Sec 1,1). In 1972, the Air Force Human Resources Laboratory (AFHRL) began applying LCOM when looking at the manpower associated with developmental weapon systems (29). In the same year, AFSC used it "to consider the impact of trade-offs between various types of resources" during the early phases of acquisition programs (60:Sec 1,1). LCOM received official recognition in 1974 when HQ USAF approved the model for use in determining aircraft maintenance manpower requirements (18). Later the same year, the Air Force Test and Evaluation Center (AFTEC) discovered the model and began using it in the test and evaluation of weapon system performance (29).

LCOM has been updated regularly since 1974, and its usage has continued to grow (18). Clark notes that the widespread acceptance of LCOM in the Air Force community is evidenced by the fact that it is now part of a standard Air

Force data system, ADPS-14 (19:10). In actual fact, LCOM is one of a number of subsystems which comprise ADPS-14 (The LCOM System). Other subsystems within ADPS-14 include the data preparation subsystem, the data structuring subsystem and the data base interface subsystem (60:Annex J,4).

In addition to those organizations already mentioned, Air Force users of the model now include MAC, SAC, USAFE, PACAF and AFCC. In addition, a number of commercial organizations, including Grumman, General Dynamics, McDonnell Douglas and Lockheed, have also adopted LCOM to look at issues relating to the operational availability and supportability of new weapon systems (29). The LCOM system is managed, within the Air Force, by the Air Force Management Engineering Agency (AFMEA) and the model software is maintained, on their behalf, by a GSA contractor, tasked with ensuring that LCOM keeps pace with changes in the logistics concepts of new weapon systems (29).

Purpose of the Model

LCOM was originally designed to simulate the interaction of various base-level logistics resources and assess their impact on aircraft sortie generation capability (19:1; 11:1). Its initial use, therefore, was as a maintenance policy analysis tool. Clark notes that since then LCOM has become "institutionalized" within the Air Force and is now primarily used by the "manpower community" to calculate direct aircraft

maintenance manpower requirements (19:1). The aim in applying LCOM in these manpower studies is to find the lowest manpower level, for each Air Force Specialty (AFS) defined, that just achieves the desired sortie rate (11:1).

Boyle notes that LCOM is also used in a variety of other studies. In these cases, he believes, the main motive for applying the model is to determine the best mix of logistics resources needed to support a weapons system under defined operating conditions. These resources can include personnel, facilities, spare parts or support equipment (11:1).

General Characteristics of Model

As mentioned previously, LCOM is a discrete event, Monte Carlo simulation model. It is written primarily in Simscript II.5 (29). LCOM is called a Monte Carlo simulation because in order to introduce demands for unscheduled maintenance, the model makes random draws from equipment failure distributions (11:3). The "standard" version of the LCOM system, maintained by AFMEA, runs on IBM 9377-090 minicomputer. However, a variation of the standard version of the model, developed by ASD/ENSSC (Systems Capability Branch), can now be run on seven different platforms including VAX minicomputers, Sun Workstations and IBM compatible 80386 DX personal computers (29).

LCOM is able to simulate a full range of activities within an aircraft maintenance organization, including usage

of facilities, spare parts, maintenance personnel and support equipment. In fact, in principle, the model can be applied to any situation that can be represented as a network of tasks (74:9). The network describes the interrelationships between the tasks to be completed, the resources required for each task, the task sequence and duration, and their probabilities of occurrence (19:6).

Input Data. LCOM requires the following data in order to operate (139:2):

1. Daily mission schedules--defining how many aircraft are to fly, when and for how long.

2. Main aircraft servicing networks--defining the tasks, time and resources needed to prepare and launch an aircraft at its scheduled time and service it on return.

3. Corrective maintenance networks--defining the tasks, time and resources needed to repair each subsystem when it fails.

4. Failure rates--defining how frequently corrective maintenance is likely to be required on each subsystem.

5. Resource quantities--defining the number of aircraft by type, men by AFS and shift, and the quantity of spare parts and support equipment (AGE) needed.

LCOM Structure. LCOM consists of three major components parts which interact in order to model aircraft flying operations, maintenance functions, and resource constraints (58:6). These components are the (58:6):

1. Input Module (preprocessor),

2. Main Module (simulator), and

3. Post Processor Module (report generator).

The Preprocessor. The Input Module translates the data supplied by the user into a format that can be used by the Main Module (30:4). The Input Module does this by separating the user supplied data into one of two files. Data relating to the maintenance environment of the simulation, such as component failure rates, scheduled and unscheduled maintenance procedures, mean service and repair times, and resource requirements are transferred to an initialization file (maintenance data base). Similarly, the portion of data relating to the operational scenario, for example, the number of Primary Authorized Aircraft (PAA) for each mission, mission takeoff times and flight duration is used to form the exogenous file (operations data base) (58:9-14).

The Main Module. The main module is the actual simulation program. Using the data in the initialization and exogenous files, it portrays "the interaction of aircraft operations, maintenance functions, and resource constraints and provides a statistical summary of the simulation results" (58:6).

Figure 7 (58:8) depicts how an LCOM simulation works. When the flying schedule calls for aircraft to start mission preparation, LCOM assigns aircraft from the available pool

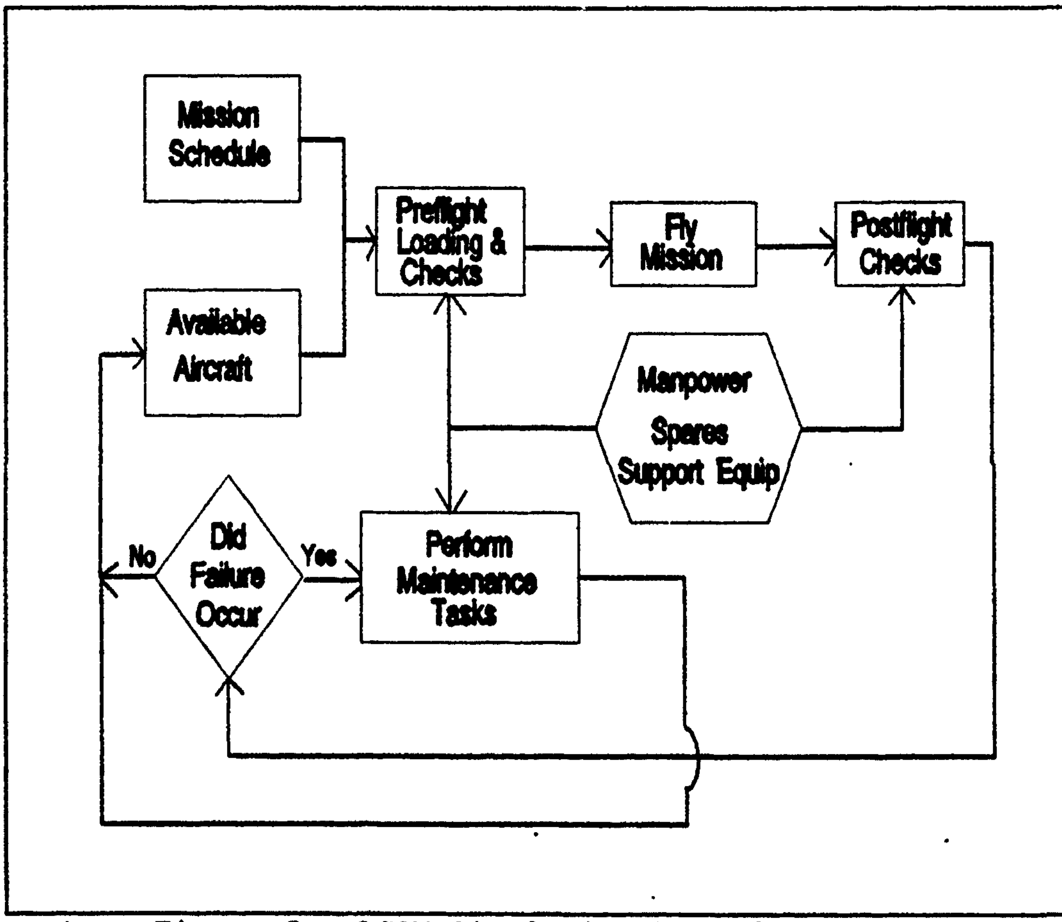

Figure 7. LCOM Simulation Procedure (58:6)

for the mission. Each aircraft then passes through the preflight check network. During this processing, LCOM uses men, spare parts, and support equipment as needed to perform maintenance actions. If all available manpower is already engaged in aircraft maintenance activity, LCOM delays the next mission until maintenance manpower is available. If aircraft are ready for launch at their scheduled takeoff time, they fly for the specified mission length and then return for processing through the postflight check network.

After postflight, LCOM returns the aircraft to the available aircraft pool (58:7).

LCOM induces component failures by the use of a failure clock. The model maintains a failure clock on each aircraft subsystem. The failure rate is usually expressed as the mean sorties between maintenance actions (MSBMA) or flying hours between maintenance actions. As each sortie is flown the failure clock is decremented by one or by the actual flying hours if the clock is expressed in terms of mean flying hours between maintenance actions. When the failure clock reaches zero the particular component fails, and the value of the failure clock is reset (19:19). The failed component is then processed through the corrective maintenance network and uses men, spare parts, and support equipment as necessary to perform the corrective maintenance. Upon completion of all corrective maintenance activity, LCOM allows the aircraft to continue with mission processing. However, if corrective maintenance delays an aircraft beyond its scheduled takeoff time, LCOM cancels the associated mission and returns the respective aircraft to the available aircraft pool (58:8-9).

After the simulation is completed, the main program provides statistical data in the form of a Performance Summary Report (PSR). PSR statistics include the number of flying hours, number of sorties requested, number of sorties accomplished, manhours (by AFS) used, manpower utilization

rates (by AFS), and parts (by WUC) consumed, generated, or backordered (58:15).

Post Processor. The Post Processor Module can, optionally, produce a number of different output reports which summarize activity over the entire period of the simulation. These reports include manpower matrices, which show demands for personnel by AFS and time of day, and spare parts, support equipment and facilities usage and availability (30:5). Boyle notes that the manpower matrices and parts reports "are particularly important in manpower modeling with LCOM" (11:6).

The relationship between the three LCOM modules and the input/output data is illustrated in Figure 8.

Supporting Programs. Boyle notes that to assist the main model components "a number of supporting programs are available to aid the data build-up process of LCOM" (11:4). The Data Preparation and Data Structuring subsystems extract historical weapon system failure and maintenance task data from the Maintenance Data Collection System (MDCS), the Core Automated Maintenance System (CAMS), and other automated data bases, to help build the input data files (37:Ch IV,8-10).

Model Assumptions

Cronk and others believe that one of the main reasons why LCOM has endured for over 20 years, despite the

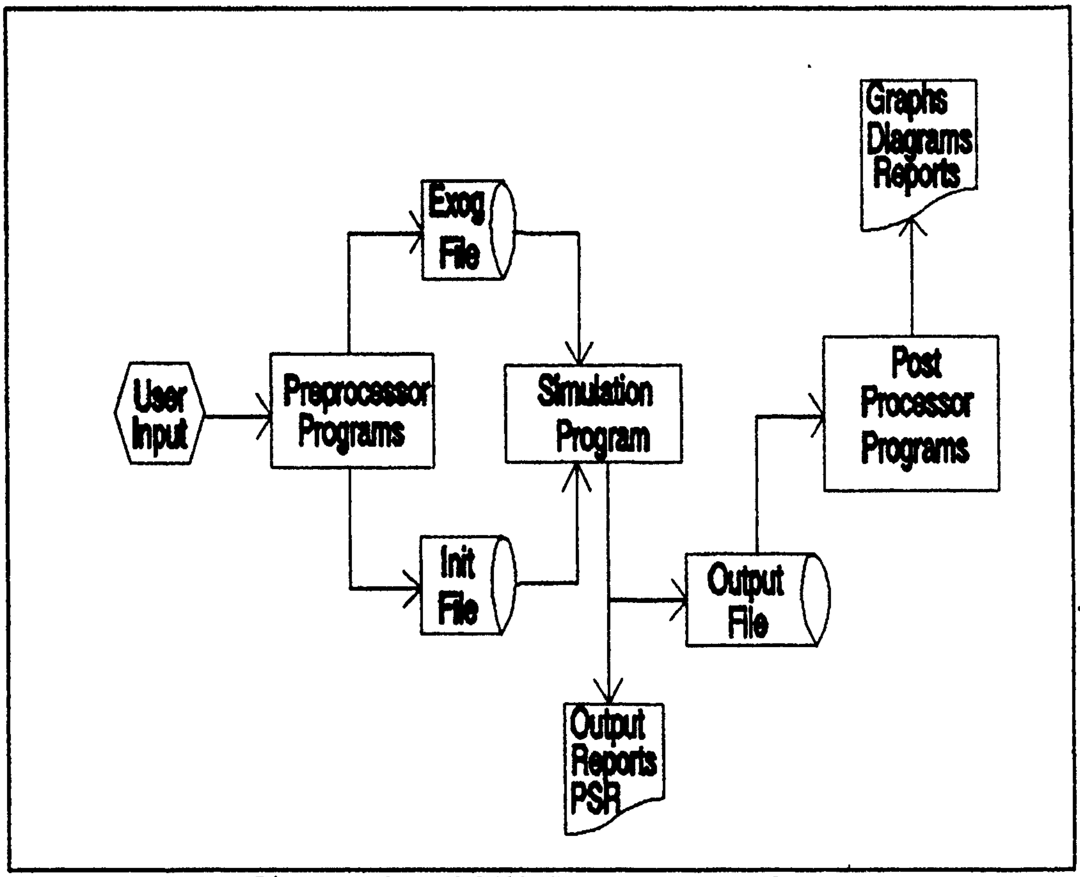

Figure 8. LCOM Structure (58:8)

competition provided by smaller, faster and more specialized simulation models (such as TSAR and AMTAF) is because it has few basic assumptions coded into the model (29; 18). The lack of restricting assumptions allows LCOM to model any specific weapon system. If additional or weapon specific assumptions are required, such as those relating to cannibalization policies, substitute resources, hot refueling, two-level versus three-level maintenance, the model user can build them in when constructing the network (29).

The few assumptions made by the model relate to the sequencing of events in the simulation module of the program. The program reads the user generated mission schedule, one mission at a time. It then looks at the pool of available aircraft for an aircraft that can satisfy the mission. If a suitable aircraft is available, the program processes the aircraft through the user defined preflight check networks. If no aircraft are available, the mission is canceled upon reaching the user specified cancel time. Once the takeoff time arrives, the aircraft flys the sortie. LCOM does not simulate in-flight activity. The model does not address survivability, vulnerability or mission effectiveness issues. However, if desired, aircraft attrition or air abort rates can be entered by the user. Next, in the sequence of activities, the aircraft returns from the sortie, lands and begins the user defined postflight checks. A check is made for failures that occurred during the sortie. If none occurred, the aircraft is returned to the available pool. If failures did occur during the sortie, the program processes the aircraft through the user defined maintenance and repair networks. Since LCOM is a queuing model, if resources required to perform a maintenance task are not available the program will wait until the resources, whether they be personnel, support equipment, facilities or spare parts, become available (29).

Uses of the Model

Although principally a manpower analysis tool, LCOM is used throughout the Air Force for a number of different purposes. SPOs use the model to estimate manpower requirements for evolving weapon systems. The model is also used in its more traditional role by MAC, SAC, TAC, USAFE and PACAF to determine the maintenance manpower requirements needed to meet planned missions for existing weapon systems (29).

However, LCOM is more than just a manpower model. For example, ASD/EN uses LCOM to verify the supportability and maintainability of major weapon systems (139:1). Logistic resource allocation decisions are evaluated by the Air Force Logistics Management Center (AFLMC) using the model. Air Force Test and Evaluation Center (AFTEC) uses LCOM to assess the operational suitability of weapon systems. AFTEC also developed an LCOM model of the space shuttle to evaluate its availability when the Air Force planned to operate it from Vandenberg AFB (29). In other applications, HQ TAC has used LCOM to model a munitions buildup shop. The model has also been used in more mundane roles, such as a study conducted by the Air Force Maintenance, Supply, Manpower and Munitions Management Engineering Team (AFMSMMET) which evaluated the number of vehicles needed in the Wright Patterson AFB base taxi system to satisfy various route schedules (29). LCOM can also be used as a spares assessment tool. ASD/ENSSC has

investigated the use of LCOM to provide input to the Dyna-METRIC model in order to identify spare parts requirements. By holding maintenance manpower, support equipment and facility resources fixed during a simulation run and constraining spare parts only, LCOM can also be used to assess the sortie generation capability and sustainability of War Readiness Spares Kits (WRSKs). However, AFLC does not use LCOM in this capacity because Dyna-METRIC (an analytical model) is much more efficient in performing the task (29).

Another important application of LCOM is its ability to evaluate policy decisions. LCOM has been used in this role to assess the effectiveness of two-level versus three-level maintenance; to determine whether functional check flights (FCFs) should be used; and evaluate combat (quick) turn methodologies (29).

Model Data Sources

The input data needed to run the LCOM model is obtained from a variety of sources. However, the data essentially falls into two different categories--maintenance environment and operational scenario, which LCOM divides into two separate input files. The operational scenario information includes a day-by-day list of available aircraft takeoff and cancellation times, sortie lengths and munitions loads. It is this information that drives the simulation and increments

the event clock. User Commands provide the majority of information needed to define the operational scenario (29).

The source of maintenance data, on the other hand, depends on the nature of the study being undertaken and the stage in the acquisition or deployment life cycle of the weapon system. During acquisition, for instance, the development of the maintenance database is an iterative process. During concept analysis, simple generic maintenance databases are built with task and failure data estimated, principally, by engineers based on Air Force experience with similar subsystems in existing aircraft plus a factor which accounts for any design differences (139:2). During the demonstration/validation phase the generic maintenance data is replaced with information on comparable systems obtained from MDCS or CAMS. Then, during engineering and manufacturing development, the comparable system data is replaced with contractor generated Logistic Support Analysis Record (LSAR) data (29). Once the aircraft enters production and is turned over to the using Command, the LSAR data is replaced with actual historical maintenance data on the system, once again obtained from MDCS and CAMS, and LCOM is used to determine maintenance manpower requirements in the Command (29). To expedite the building of the maintenance database, LCOM has a data preparation subsystem, consisting of a number of COBOL programs, that can select, extract and combine data from MDCS, CAMS and LSARs (29; 28:1).

Shortcomings of the Model

Data Intensity. As mentioned previously, one of the features of LCOM that has contributed to its widespread acceptance and endurance has been the fact that the model has few "built-in" assumptions. While the sparsity of assumptions makes the model applicable to a wide range of applications, the user must pay the penalty for this generality but entering a substantial amount of detail to construct the controlling networks (29). Cronk estimates that it can take anywhere from one to 12 months, depending on the system being modelled, to build input data bases.

Hildebrandt makes a similar observation in his review of a number of maintenance manpower models used by the Army, Navy and Air Force, including LCOM. He notes that as models become more flexible they depend more on detailed data input to define modeling relationships and "less on the assumptions embodied in the model" (97:4). He further observes that the consequence of this is that models become more of an analysis framework than true models (97:4). His comments would seem applicable to LCOM.

Execution Time Problems. Proponents of the LCOM model claim that the most common criticism of the model is its slow execution time. This issue is, of course, closely related to the model's data intensity. Hoeber claims, for instance, that LCOM is "...huge and cumbersome...and one-half to two hours CPU time are required for one LCOM run" (100:116).

While run time is very much dependent on the complexity of the data base being used in a simulation and the type of computer on which it is run, Clark found in a 1987 study which compared LCOM against the Theater Simulation of Airbase Resources (TSAR) model, using comparable databases and a NAS 7000 computer, that TSAR's execution time was between five and eight times faster than LCOM's. Clark notes that while execution speed is not an overriding consideration when selecting a simulation model, it does have important implications for the analyst or manager. Faster execution times, in some cases, can mean the difference between a turnaround on the same day or having to wait overnight for a run. This is particularly important when numerous simulations must be conducted, and "the input of each simulation depends on the results of the previous simulations" (19:57). Clark notes that this is usually the case when performing manpower studies (19:57). Also, because computer time is not free, faster execution times mean savings in computer operating expenses. Alternatively, the computer time saved through faster execution can be used to conduct additional simulations which will allow a more thorough analysis of the subject area (19:57). This can be particularly important when complex policy issues are being examined.

Policy Analysis Limitations. Hildebrandt suggests that the structure and development history of LCOM restricts its

ability to be used as a capable policy analysis instrument. To be a useful in addressing a broad range of policy issues Hildebrandt believes a Monte Carlo simulation model must have "a flexible program structure and accessible and easily modifiable code" (97:43). He considers that these particular characteristics are more likely to be associated with programs that have been written by a single developer, or "honcho", in a general-purpose language (such as Fortran), rather than ones involving team development efforts and a specialist computer language (such as SIMSCRIPT) as in the case of LCOM (97:43-45).

Training Time. LCOM is a complicated model and, as noted previously, has substantial input data requirements. Cronk indicates that, depending on the background of the analyst, it can take 12 months or more of full time training to make a person reasonably proficient at using LCOM (29). Additionally, although use of LCOM is widespread within the Air Force, the number of operators with expert knowledge of the model is very small. This has important implications for the USAF if an unexpected number of the experts separate from the USAF at one time. The situation is exacerbated by the fact that the USAF does not have a formal course training personnel in use of the model, relying solely instead on on-the-job training (29).

Modeling Capability Limitations. Critics of LCOM have always been keen to point out the capability limitations of

the model, particularly when comparing it to newer simulation models such as TSAR and All Mobile Tactical Air Forces (AMTAF) model. For example, LCOM has limited wartime modeling capabilities. It cannot capture the impact of airbase attacks or chemical warfare and, because it considers only a single air base operation, it cannot model lateral resupply amongst bases or deferred or rear area maintenance (19:58). Additionally, LCOM does not simulate in-flight activity. It does not address survivability, vulnerability or mission effectiveness issues during sorties (aircraft attrition or air aborts can be modeled) (29). Furthermore, its manpower calculations do not take into consideration work centers whose manning levels do not directly constrain sortie generation capability (11:13-14). LCOM also has limited ability to handle cross training or task analysis issues (67:2; 11:8). Furthermore, LCOM is not particularly good at determining spares requirements because it does not consider cost in identifying the spares needed to achieve a specified aircraft availability level (29). From an operator's perspective, unlike TSAR and other more modern simulation models, LCOM does not allow multiple replications of a simulation to be made in one computer run; each replication must be handled separately (19:39).

<u>Lack of Model Portability.</u> Another criticism levelled at LCOM relates to the fact that the model is programmed in SIMSCRIPT. This means, of course, that the computer system

hosting LCOM must have a SIMSCRIPT compiler. Noble claims that this greatly reduces the choice an agency intending to use LCOM has in buying a computer, and restricts the model's portability (130:5). However, this problem is becoming less of a concern with advances in computer technology. Also, ASD/ENSSC has recently translated LCOM for use on an IBM compatible 80386 machine. Although execution time, at present, is unacceptably slow when LCOM is being used on a regular basis, ENSSC hopes that continued advances in microcomputer technology will make a microcomputer version of LCOM a viable proposition in the not too distant future (29).

Strengths of Model

Decision Maker Confidence. LCOM has been used by the Air Force on a continuous basis since the early 1970s. The model was first validated by TAC in 1974 in a field test involving a squadron of F-4Es (18). An operational scenario was defined and LCOM was used to estimate a daily sortie generation rate. The F-4Es were then flown as close as possible to the predefined scenario. Although the exercise was terminated earlier than planned, because of a squadron tasking, TAC declared the exercise a success and concluded that LCOM provided acceptable results (18). According to Drake and Wieland, LCOM has been validated a number of times since then by comparing real world data against simulation results (60:Ch I,3). The model is now used throughout the

Air Force for assessing maintenance manpower requirements and addressing other logistics issues, and has achieved widespread acceptance. Noble goes as far as to say that LCOM has become "institutionalized" within the USAF (130:4).

Range of Applications. As noted earlier in this section, LCOM has few assumptions built into the model. This allows LCOM to be used to model a general range of activities, both aircraft and non-aircraft related. Fisher suggests that LCOM can be applied to any situation that can be represented as a network of tasks (74:9). The Air Force has used LCOM to simulate situations ranging from an on-base taxi service, through determination of maintenance manpower requirements for ground communications equipment to an evaluation of the operational availability of the Space Shuttle (29).

Model Capabilities. Despite the mouthings of its critics, LCOM has a considerable range of features that allow it to provide detailed and comprehensive analyses of situations, whether these be squadron maintenance manpower determinations or policy investigations. For example, it can model non-sortie related equipment failures, a range of cannibalization strategies, and consider air aborts and attrition during sortie activity. LCOM can also produce a number of "meaningful measures of merit" in assessing the overall performance of the weapon system being modelled. These measures include sortie generation capability, aircraft

availability, and mission capable rates. The model also has an extensive array of data extraction and consolidation programs which aid in the building of input data files. These programs can obtain information from the MDCS and CAMS, as well as MIL-STD-1388-2A LSARs (28:1; 44:Sec 1,1). The model's post processor modules also allow a comprehensive array of manpower and resource utilization statistics to be produced. Additionally, LCOM can be used as a spares requirements determination tool or, using different input information, it can assess the capability of a WRSK to sustain squadron combat operations (29). Finally, LCOM can be used to evaluate policy issues such as whether two-level or three-level maintenance should be used in particular situations (18).

Model Maintenance and Use Costs

It is difficult to make an assessment of the costs incurred by the Air Force in the maintenance and operation of LCOM. This is because there is no such thing as a "typical" LCOM analysis on which to base an estimate. LCOM is an operational system as opposed to a functional one and, as such, studies are conducted on as required, case-by-case basis. The model does not process standard historical data files or incorporate a standard data base.

Notwithstanding this, it is not hard to determine that substantial costs are involved in running the model. For

instance, LCOM only runs efficiently on mainframe and minicomputers, and CPU time for these machines is expensive. In most cases, however, computer operating costs are hidden from the operating organization because it uses its own computer system and LCOM simulations are just one of a number of tasks being performed. Generally, computer operating costs only become visible when an organization does not have its own computer and instead must rely on a Command or product division central computer facility to run the model. In these situations, a "user pays" system is usually in operation and, consequently, the model user is charged for the CPU time consumed.

Manpower costs are also difficult to estimate. Once again this is due to the fact that a "typical" LCOM simulation does not exist to provide a baseline for calculations, and also because there is no formal OPR sponsored training course for model operators. As a consequence, operator training must be provided on-the-job. The leader of the ASD/ENSSC LCOM Group, Mr Dick Cronk, estimates that it takes in the vicinity of 12 months to train a person to use LCOM, assuming he or she has a suitable background in systems engineering and aircraft maintenance (29). Moreover, when the model is applied, the operator must spend a considerable amount of time gathering operational scenario and maintenance data needed to build the model data bases and networks, notwithstanding the assistance provided

by the model's Data Preparation Subsystem and the Automatic Network Generator Program. Cronk estimates that the data preparation stage can take anywhere from one to 12 months (29).

HQ AFMEA/MEIL is the ADS manager responsible for maintenance, modification and documentation of LCOM (44:Sec 1,1). AFMEA uses a GSA contractor to maintain and modify the LCOM source code. However, LCOM is a mature and reasonably stable software package and no major modifications to the model have been made in recent times.

Model Improvement and Validation

LCOM has undergone considerable evolutionary development since it was first introduced to the Air Force in the late 1960s. The first major improvements to the original model developed by AFLC and Rand were made during the conversion of the LCOM simulation software from SIMSCRIPT I to the SIMSCRIPT II programming language during the period 1975 to 1977 (60:Sec 1,1). This effort, which was sponsored by HQ USAF/LG, improved the efficiency of the model and added a number of new user features. The resultant software product was called LCOM II (60:Sec 1,1).

At about the same time, in a separate project, efforts were underway to provide LCOM with a preprocessor capability that would allow it to automatically extract MDCS data to help in the building of input files. This project was

successfully completed in 1978 (29). In the same year an attempt was made to standardize the LCOM II software so that it could be implemented on a number of minicomputer systems other than the Honeywell or IBM machines (60:Sec 1,1). Concurrent improvements were also made in the efficiency of the software and its memory requirements (60:Sec 1,1). In 1979, the simulation software was once again upgraded. Changes made included improvements to the model's data editing features and an enhancement in its ability to handle cannibalization of spares (60:Sec 1,2). In 1981 another software upgrade was completed. This time the Input Module's diagnostic features were upgraded to provide better information to the user in the event of a fatal execution error occurring. New features were added to the Main Module to improve its flexibility and give more realism to the simulation, and enhancements were made to the parts post processor (60:Sec1,2).

In 1981, HQ USAF issued a project directive which established a management structure for LCOM and promulgated the model as a standard Air Force automated data processing system, ADPS-14. The next significant development affecting LCOM occurred in 1983 when ASD/ENSSC wrote a program to extract DARCOM Pamphlet 750-16 LSAR data and format it for input to LCOM's Automatic Network Generator Program. This enhancement was subsequently included in the standard version of LCOM maintained by AFMEA (28:1). ASD/ENSSC also added

attribute capabilities to the model in 1984. AFM 171-605 VOL II-E notes that this feature allows the user "to assign values to specific aircraft...and make decisions based on the values used dynamically within the network" (45:Sec 2,9). For example, the amount of fuel on an aircraft could be maintained as an attribute. Then, in 1988, ASD/ENSSC began a project which aimed to allow LCOM to be implemented on a number of different computers, including an IBM compatible 80386 machine. The project achieved its aims, although the microcomputer version of model proved to be too slow for practical implementation (29). During the same period, MIL-STD-1388-2A replaced the DARCOM pamphlet as the standard format for contractor provided LSAR data necessitating the revision of the LCOM Automatic Network Generator program to use different input data. Subsequently, in 1989, the program used to automatically create LCOM input data from LSARs was modified to accommodate the new record format. This modification was also incorporated in AFMEA's standard version of the model (29).

Although a number of modifications have been made to the LCOM software over the years, the original structure of the model has been maintained. Moreover, the modifications have resulted in definite improvements to the model; they have increased its speed of execution and user friendliness and also reduced the amount of time required to gather data for, and prepare, a simulation.

In relation to model validation, as mentioned previously, the first formal validation of LCOM was carried out in 1974. In this study, LCOM was used to predict the sortie generation capability of a squadron of F-4Es deployed to Seymour Johnson AFB. Although the exercise had to be terminated earlier than expected, because of a squadron tasking, TAC was satisfied with LCOM's predictions and declared the exercise a success (29). Drake and Wieland note that LCOM has been validated numerous times since then using historical data from several different weapon systems (60:Sec 1,3). They claim that these studies have verified "the solidarity of the software logic" (60:Sec 1,3). There can be little doubt that LCOM has achieved widespread recognition and acceptance within the Air Force as a logistics analysis tool, and it appears destined to "endure" for many years to come.

VI. Summary and Conclusions

Chapter Overview

This chapter begins by providing a summary of the characteristics of the LCC models reviewed in chapters three, four and five. It then describes, briefly, the current status of LCC within the USAF, as perceived by the author, by reviewing the general changes that have taken place in LCC models and management since the last major reviews were conducted in the 1970s and early 1980s. The chapter concludes by providing a synopsis of the major issues likely to impact LCC in the near future.

In drawing conclusions, the author was acutely aware of the risk of over-generalizing, particularly in view of the fact that LCC is such a broad subject area and this review has covered only a small percentage of the total number of the LCC models currently being used by the USAF.

Summary of LCC Model Characteristics

The LCC models reviewed by the author were broadly classified into three groups; O&S models, comprehensive LCC models and specialized models. This classification scheme was devised more for analytical convenience than because of fundamental differences between the models in the various categories.

For instance, using the model classification scheme defined in chapter two, it can be seen that the LSC and LCCH models are classical accounting models, whereas the ZCORE model is a cost factor or optimization model. Similarly, both the MLCC and the PRICE family of models are parametrically based, whereas the CASA model combines accounting and simulation capabilities. Dyna-METRIC is slightly different from the other models in that it is based on an equation known as Palm's Theorem. It is an optimization model, but its method of operation is more closely aligned with accounting models. On the other hand, LCOM is a classic simulation model.

The general characteristics of the models reviewed are summarized in Figure 9. The chart indicates that the majority of models reviewed are PC based. Although a PC version of LCOM has been developed by ASD/ENSSC its execution speed is too slow to make it of practical use to analysts. The chart also highlights the fact that none of the models reviewed consider the disposal phase of an equipment's life cycle. Recent work in the area suggests that disposal costs can be quite substantial, and considering current community attitudes towards waste disposal and conservation, retirement costs are likely to continue to increase in the future. Accordingly, disposal costs should be taken into consideration in LCC analyses.

Figure 9 also indicates that few of the models reviewed

Models	Type of Model	Microcomputer Based	LCC Phases Covered: RDT&E	LCC Phases Covered: Acquisition	LCC Phases Covered: Operation & Support	LCC Phases Covered: Disposal	Formally Validated	Op Availability Measure	Budget Estimates	Warranty Consideration	Risk Analysis	Inflation Adjustment	Discounting	Sensitivity Analysis Cap.	User Friendliness	User's Manual	Data Intensity
LSC	A	✓			✓		✓	✓	✓					Good	Fair	Fair	H
LCCH	A	✓			✓			✓		✓			✓	Poor	Poor	Poor	M
ZCORE	C	✓			✓					✓		✓	✓	Poor	Fair	Fair	M/L
CASA	A/S	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	Good	Good	Good	M
PRICE (H, HL, M, S)	P		✓	✓	✓			✓	✓			✓	✓	Good	Fair	Fair	M
MLCC	P	✓	✓	✓	✓							✓	✓	Fair	Poor	No	M
Dyna-METRIC	A	✓		✓	✓		✓	✓		N/A		✓		Fair	Fair	Fair	H
LCOM	S				✓		✓	✓	N/A	N/A		N/A	N/A	Fair	Poor	Fair	H

KEY:

P - Parametric
A - Accounting
C - Cost Factor
S - Simulation
H - High
M - Medium
L - Low
Good · Fair
Poor · N/A
✓ Yes · No

Figure 9. LCC Model General Characteristics

have been formally validated. In fact, LSC is the only model that has been examined as part of a formal validation effort, although both Dyna-METRIC and LCOM are shown as being validated. These models, owing to their rather specialist nature, have been validated using field tests rather than paper studies. A number of the models also have an operational availability measure that estimates the proportion of time that a weapon system should be available for use. The models that possess this feature generally calculate weapon system availability as a function of the number of spare parts held at the organizational level. In the case of LCOM, the availability of maintenance manpower is also taken into consideration.

The models that incorporate a warranty feature allow certain categories of cost, such as support equipment, initial training, and repair labor, to be set equal to zero for each year that equipment is under warranty. However, the warranty option of several models, particularly the LCCH model, need to be used with caution because of assumptions they make about the type of warranty purchased, e.g., all depot maintenance will be done at contractor expense while the system is under warranty, and the Air Force will pay the cost of transportation during this time.

The chart also highlights the fact that only one of the models reviewed, the CASA model, has a risk analysis capability. Risk analysis uses probability distributions to

describe the uncertainty in key cost and reliability parameters, such as unit cost and MTBF. The feature is particularly useful for allowing decision makers to gauge the effect of basic model assumptions. Finally, Figure 9 emphasizes the data intensity of the LCC models reviewed. The amount of time needed to gather input for LCC models is one of the main problems that must be addressed in the 1990s.

General LCC Issues

Earlier Identified Problems

This section details the problems that have been identified in previous studies of Air Force LCC models and investigates what action, whether specific or general, has been taken to resolve the issues raised.

Previous Studies. Two main groups have investigated the status of LCC models used by the USAF in the past. Between 1973 and 1977, the Joint AFSC/AFLC Commanders' Working Group (JCWG) on LCC conducted a number of studies which looked at the type of LCC models then available within the USAF, examined how the various models differed, and investigated the nature and extent of the models' deficiencies in meeting LCC analysis needs and how some of these deficiencies might be overcome (23; 24; 25). Later, in 1978, Rand evaluated the LCC models most commonly used by the Air Force in a study on life cycle analysis applications and methods. The Rand study focused on models that were applicable to the estimation of

O&S costs, looking in particular at the ability of the models to estimate the budgetary and other resource cost impacts "of proposed changes in an aircraft system's performance, operational, logistics, or other support characteristics" (121:2).

Another significant study, although not focusing exclusively on LCC models, was undertaken by Long in 1983 (120). Long looked at the application of LCC in a dynamic defense environment and commented on what he saw as a "credibility gap" in the application of the philosophy (120:25).

<u>Deficiencies Detected</u>. The LCC deficiencies noted by the three authors can be characterized as either model related or institutional.

<u>Modeling Problems</u>. The modeling problems identified were as follows:

1. <u>Insensitivity to Performance and Design Parameters</u>. The most common type of LCC model used during the time of the JCWG studies (and still today) was the accounting model. As a general rule, accounting models calculate O&S costs as a function of reliability and maintainability characteristics such as MTBF and maintenance manhours per flying hour. The JCWG noted that the accounting models they reviewed did not relate O&S costs to system or equipment performance and design parameters, such as material type, ease of manufacture, weight, speed or range (23:8-9).

The JCWG suggested that this lack of model sensitivity to performance and design parameters was of particular concern since the majority of conceptual planning and design trade studies evaluate alternative values of such parameters, and it is during the development phases that the majority of subsequent ownership costs become "locked-in" (23:9).

2. Complexity. The JCWG also noted that the application of many LCC models, particularly those of a general purpose nature, was severely limited because they involved a large number of parameters, and parameter definitions were unclear (23:9). They suggested that the large number of input parameters, in addition to making model data requirements extensive, obscured the typically small set of "cost driving" parameters that have a pivotal impact on LCC (23:9). Similarly, the complexity of the models made it difficult to gather required input data. Moreover, the extensive data requirements made the job of scrutinizing data prior to model input, in order to ensure its veracity, extremely time consuming. The JCWG believed that the tendency towards large input data requirements related to a model builder's desire "for an all-inclusive cost structure" that will make his model applicable to a variety of decision issues (23:9).

3. Lack of Sensitivity to Wear-Induced Failures. The models reviewed by the JCWG tended to assume that failures occurred at random and, consequently, the

number of failures was directly proportional to the number of hours of equipment operation. The JCWG noted that while this assumption was valid for some devices, such as electronic components, it is not for items which are subject to long term wear-induced failures. The JCWG research showed that in situations where the frequency of wear-induced failures cannot be predicted, e.g., the occurrence of failures due to aircraft structural fatigue, the costs related to such failures are typically ignored by LCC models. As a result, the JCWG concluded, models ignoring wear-induced failures cannot be used to gauge the impact of alternative designs on the costs of such failures (23:10).

4. Model Design Problems. Marks et al., from Rand, also commented on the inconsistent treatment and definition of individual cost elements between models. This, he suggested, makes it "difficult to assure that a dollar's worth of one resource (cost element) is equivalent to a dollar's worth of another resource" (121:78), and virtually impossible to cross-check the results of two different LCC models for consistency. Marks also noted that the LCC models reviewed tended to be designed to provide an indication of the relative cost differences between program options, rather than absolute variations, or highlight a particular area of life cycle cost without reference to the total (121:2).

.Marks also highlighted the insensitivity of LCC models to important cost driving factors--particularly those

relating to USAF institutional and support policies, e.g., levels of maintenance, and their "poor representation of the causal relationships governing the resource demands and costs of aircraft systems" (121:2). Also lacking, he suggested, were system effectiveness measures, such as the percentage of time the equipment is operationally available. Finally, Marks was critical of the models reviewed because of their inability to distinguish between intermediate resource demands, e.g., direct maintenance manhours, and final resource requirements, e.g., the number of maintenance personnel needed (121:2).

<u>Institutional Problems</u>. Marks and Long also commented on what they same as a number of institutional impediments restricting the development of LCC.

1. <u>Lack of LCC Incentives</u>. The Rand investigators found that a number of institutional flaws were inhibiting the application and use of LCC. Firstly, they found that there was limited incentive for those involved in acquisition programs to make trade-offs between cost and system performance or schedule, or between acquisition costs and ownership costs. Long noted that, in particular, Program Managers (PMs) had no incentive to address the issue because it was not an evaluation criterion in their effectiveness reports (120:33). Rand also found difficulties in firmly linking the allocation of resources in the Planning,

Programming and Budgeting System (PPBS) to the results of LCC analyses (121:1).

2. Data Related Problems. The JCWG found that the inability to gather required input data was one of the main reasons why LCC models were not being used more extensively in the 1970s. Rand commented on the particular difficulties caused by the lack of an "integrated historical data base at the aircraft component level" (121:vii). They noted that at the base level, historical information on component reliability and maintainability was reported by work unit code (WUC), whereas in the supply system and at the depot maintenance level spares information was tracked by stock number, and there was no standard cross reference system to match-up the two recording systems. The differing nomenclatures created a data collection problem (121:vii).

Long too believed that data was a particular problem in LCC analyses. He stated that, "There is either too much or too little; it is in the wrong form or format; and its accuracy is questionable." (120:35). Long highlighted the fact that there are over 140 separate automated and manual data collection systems in the Air Force containing O&S cost information (120:35). The abundance of data creates its own problem. Long suggested that for the data to be useful, the analyst must know how it was collected, what cost elements are included and not included in particularly cost categories, and what assumptions are applicable. Long

suggests that with the proliferation of data sources, this background research by itself can be a monumental task (120:36). Long suggested that the problem should be alleviated by the introduction of VAMOSC.

Another data problem highlighted by Long relates to the fact that many O&S costs used in LCC analyses must be derived owing to the fact that large portions of the DOD budget are not apportioned to individual weapon systems or MDSs. This, he suggested, raised concerns about the reliability of the derived data and the basis of the apportionment techniques (120:37).

3. Lack of Control Over LCC Program. In his research Long noted that there was no mechanism to ensure that the potential benefits of LCC were actually realized in Air Force programs. This concern stemmed from the fact that no USAF organization monitored the day-to-day implementation of LCC management, and separate procurement (AFSC) and support (AFLC) responsibilities existed. In other words, there was no single individual or command responsible for a weapon system over its entire life cycle (120:28-29,34). Long believed that the PM should work for the user Command.

4. Lack of Program Stability. Long pointed out that both the Air Force and Congress contribute to program uncertainty; the Air Force by continually modifying its requirements, and the Congress by continually requiring the service to justify its requirement. Stability, Long

beleived, could be added to the process by clearly defining requirements early in a program, and by introducing multi-year budgeting and contracting (120:30-31).

5. The People Problem. Long emphasized in his study that he believed there was a lack of trained, experienced analysts in the LCC community. Long suggested that analysts seldom spend an extended period in the one position if they stay within the DOD, and because they work directly with business and industry they are often lured aware by the better salaries and fringe benefits offered in the private sector. Long also indicated that many projects are assigned to a single analyst. He believed that no LCC estimate should be done by one person; rather, it should be the product of a team skilled "in logistics, economics, business, operations, and cost estimating" (120:35).

Changes Since Previous Studies. Several of the models reviewed by the author were included amongst those investigated in the 1970s by the JCWG and Rand. These include the LSC model, LCOM and the PRICE hardware model. These models have undergone a considerable amount of further development and revision since that time, and it was interesting to see whether the previous criticisms are still valid. For instance, the RCA PRICE model reviewed by Marks, has been extensively revised and a number of other PRICE models have been added to the family, as detailed in chapter four. The ZCORE, CASA, MLCC and Dyna-METRIC models have all

been developed since the time of the JCWG and Rand studies.

The insensitivity of LCC models to performance and design parameters remains a problem. Accounting models, including the three reviewed by the author--LSC, LCCH and CASA models, are still driven by reliability parameters. LCC estimates driven by performance and design parameters essentially remain the prerogative of parametric models, such as the PRICE family and MLCC models, which interpolate or extrapolate their estimates based on historical data. The reliability foundation of the accounting models means that they cannot be used in the conceptual development and design phases of an equipment's life cycle. In fact, unless a strong analogy can be drawn with an existing system, accounting models generally cannot be used before Phase III (Engineering and Manufacturing Development) in the acquisition cycle.

Model Complexity. The general complexity and data intensity of LCC models, particularly accounting models, remains a concern. As was noted in Chapter three, it can take anywhere from one to 12 months to gather information to run the LSC model. The LCCH and CASA models, although not quite as data intensive, still involve a considerable data gathering effort. In fact, now that the majority of LCC models are hosted on PCs, the amount of time spent by analysts in gathering and verifying data is by far the most significant expense associated with conducting LCC analyses.

Depending upon the level of detail being considered in an analysis, parametric models, such as PRICE and MLCC are usually the least data intensive, followed by cost factor models, such as ZCORE. However, if a parametric LCC analysis is being used to investigate a design down to the SRU or sub-SRU level of component indenture, the data preparation effort can, once again, be very involved.

Input Data Problems. As was the case back in the 1970s, perhaps the greatest challenge still facing LCC is the streamlining of data gathering procedures. Although the availability of data has improved since the time of the JCWG and Rand reviews, as a result of programs such as the Logistics Management Systems (LMS) Modernization Program, data gathering still remains the most challenging and time consuming task faced by cost analysts, particularly in relation to O&S costs. This situation stems from the fact the majority of data collection systems from which LCC data are extracted were not designed for use in LCC. They are principally financial accounting systems, maintenance workload planning systems, or have other primary uses. Moreover, the cost collection system that was specifically designed with LCC in mind, the Visibility and Management of Operating and Support Costs (VAMOSC) system was not successfully implemented in the early 1980s, and although, subsequent improvements have been made, a number of potential users are reluctant to give the system another chance (117).

The aims and operation of VAMOSC are addressed in detail in the next section.

Sensitivity to Wear Induced Failures. The inability of LCC models to address long term wear-induced failures, identified by the JCWG, has not been addressed in the subsequent development of LCC models, as far as the author is aware. Certainly, none of the models reviewed by the author have this capability and it is not planned for incorporation in any of the future editions of these models. In fact, the author doubts that this issue will every be able to be addressed, successfully, by any deterministic LCC model.

Model Design Problems. The inconsistent treatment and definition of cost elements in LCC models, mentioned in the 1978 Rand study, has been overcome to a large extent by the OSD CAIG publication of standard cost element structures for aircraft and various other types of equipment. Later models, such as CASA, have been developed using the CAIG structure as a basis, while older models such as the LSC have subsequently been revised to bring them closer into line with the CAIG outline. However, the alignment of cost categories in various models is still not complete as Minnick noted in a 1988 study of the CASA and LSC models, and Gooding witnessed when he compared CASA against the LCCH model in 1989 (89; 126). Additionally very few models that purport to be LCC models can truthfully claim the title. Marks comment remains

valid in that most LCC models still concentrate on a particular phrase of the equipment life cycle. In fact, none of the models reviewed by the author provided complete life cycle coverage. Even the more comprehensive models, such as CASA and MLCC, omit the costs associated with equipment disposal.

Several of the other areas where the Rand study identified weaknesses in the LCC models have been addressed, although not always as successfully as possible. For instance, most models now incorporate some type of effectiveness measure, usually system operational availability. However, in all the models reviewed by the author the availability equation omitted relevant considerations such as the effect of preventative maintenance, thereby leading to an overestimate of system availability. Additionally, the majority of the models reviewed by the author now include extensive sensitivity analysis capabilities in order to allow the identification and investigation of cost driving factors. However, the inability to distinguish between intermediate and final resource requirements, particularly in the manpower area, remains a problem.

<u>Institutional Constraints</u>. A number of the institutional constraints limiting the successful application of LCC, as identified by Marks and Long, have been overcome since the time of their studies. For instance, the requirement for major project "baselining" commenced in the

mid-1980s, as a result of the publication of DODD 5000.45 (Baselining of Major Weapon Systems), firmly establishing cost as a parameter equal in status to program schedule and performance in the eyes of Project Managers (PMs). Publication of the CAIG cost element structure guidelines has also helped to strengthen the link between LCC analyses and the PPBS. However, the CAIG has also gone to considerable lengths to explain and emphasize the differences between the two systems; LCC with its emphasis on variable weapon system costs and the PPBS being concerned with total financial costs.

However, several other problems mentioned by Long remain unresolved. For example, there is still no one individual or Command responsible for a system over its life cycle. In this regard, the creation of Air Force Materiel Command (AFMC) on 1 July 1992, can be seen as a step in the right direction, with procurement and support functions being consolidated in the one organization. A limited amount of stability has also been added to the budgeting area by making PPBS a biennial rather than an annual process. The issue of multi-year contracting is also being debated.

The People Problem. The "people problem" identified by Long also still exists to a large degree. The employment mobility of analysts assigned to SPOs is still a grave concern, although reasonable employment stability is maintained amongst personnel in the FMC and ALT staff

positions. As previously mentioned, the data availability problem has improved but not significantly. More specifically, VAMOSC, because of development and implementation problems, has not been the "panacea" it was designed to be in the O&S cost area. Consequently, analysts still go to original data sources to obtain O&S cost information. While this practice in itself is not bad, the amount of time needed to gather information from these sources is extensive and is delaying the preparation of LCC estimates. A related problem, identified by Long, concerns the nature of the data stored in these databases. Most data sources are functionally orientated and do not relate consumption of resources to MDS. Consequently, a large percentage of O&S costs must be allocated amongst the various weapon systems based on an activity measure such as the number of flying hours. Lacking specific guidance on the issue or any standard attribution formulas, analysts are left to make individual judgement regarding attribution. This situation has the potential to cause inconsistency in estimates being prepared by different analysts.

<u>The Modeling Problem</u>. The "modeling problem" also continues to exist. The author, in his investigations, noted that analysts in particular SPOs and staff functions tend to favor particular models for various historical reasons. With some notable exceptions, there appears to be a general lack of awareness amongst analysts of newer and, perhaps, more

appropriate models available. Additionally, in several cases, the author found that specific proprietary models were still being held on contract for "historical reasons" although no analysts within the particular area used the model. Contrary to Long's recommendation, a modular LCC model, employing a range of estimating techniques but using a common CES, has not been developed. However, the idea of an integrated model is worthy of further consideration.

VAMOSC

Origins of VAMOSC. The need for VAMOSC grew out of DOD concern in the early 1970s over the rapid growth in O&S costs as a percentage of the defense budget. In 1968, for the first time, the O&S portion of total weapon system costs exceeded 50 percent of the DOD budget (135:29-30). By 1974, O&S costs had escalated to nearly 70 percent of defense outlays (14:2). DOD planners finally realized that if something was not done to rein the growth in O&S costs, the DOD would soon be unable to afford to develop new weapon systems.

The first positive action came in 1975 when the Assistant Secretary of Defense published Management by Objective (MBO) nine. This document had as its stated aim to reduce O&S costs. A sub-set of this publication, MBO 9-2, titled DOD Requirements for Visibility and Management of Support Costs, tasked the services to:

1. develop weapon system operating and support cost visibility,

2. develop component level cost visibility,

3. standardize O&S cost terminology and definitions DOD-wide, and

4. institutionalize the O&S cost systems at each service. (137:2)

Recktenwalt notes that "This memorandum was the genesis of DOD VAMOSC development" (137:2).

In response to MBO 9-2, the Air Force developed two new systems to track O&S costs. In 1976, the first system, called the Operating and Support Cost Estimating Reference (OSCER), was developed on behalf of HQ USAF/ACMC. This system was designed to track and report aircraft O&S costs at the MDS level. At about the same time, HQ USAF/LEYE arranged for a contractor to develop a similar system to report O&S costs for communication, electronics and meteorological (CEM) equipment. This system was known as the Communications-Electronics Logistics Support Costs management Program (137:2).

Recktenwalt noted that although both systems operated in accordance with specifications, their rapid development resulted in sketchy documentation and only minimal provision for future configuration and programming changes. For example, the lack of memorandums of agreement (MOA) with the data systems feeding them meant that OSCER and CEM outputs could easily be invalidated if these systems changed their

logic (137:2-3). Recktenwalt also highlighted the fact that only minimal development resources were allocated to both systems. He suggested that this funding shortfall necessitated both systems relying heavily on "canned utility routines" and resulted in a less than perfect transition of the systems from contractor to Air Force control (137:3). Many of the problems experienced by VAMOSC when it was initially fielded in 1982 can be traced back to the hasty development of OSCER and CEM.

The final system incorporated in the initial VAMOSC development was the Logistics Support Cost Ranking System, K051. This system, which had originally been developed by HQ AFLC in 1967 to track "the O&S costs of components of aircraft at the National Stock Number (NSN) level" (137:3) became the core of the VAMOSC subsystem known as the Component Support Cost System (CSCS). K051 was augmented under VAMOSC to include field level O&S cost information, in addition to depot maintenance costs, and a NSN/WUC cross reference dictionary was added to reconcile the two different maintenance reporting systems used at the base and depot level.

Initial VAMOSC Composition. The initial version of VAMOSC comprised the following three systems (137:3-4):

1. Weapon System Support Cost (WSSC), D160 data system --which reported the O&S costs of aircraft at the MDS level.

2. Communications-Electronics (C-E), D160A data system

--which reported the O&S costs of ground based communications /electronics systems at the Type Model Series (TMS) level of detail.

3. Component Support Cost System (CSCS), D160B data system--reporting O&S costs of components of aircraft at the NSN/WUC level of detail.

Initial Field Experience. The VAMOSC system that became operational in 1982 was hosted on a CYBER computer at HQ AFLC and consisted of a preprocessor, VAMOH (a group of COBOL programs that processed source input data from a variety of Air Force data banks), and a series of COBOL programs that calculated costs and produced output reports in a batch mode (117:Sec 1,1). However, initial user reaction to the system was less than overwhelming. Users who logged onto the system with high expectations were confronted with numerous data fields filled with zeros, or were unable to access capabilities advertised in the user's manual. Furthermore, when reports were obtained the meaning of some of the cost elements on reports was not clear from their titles and no descriptions were available in user documentation (66:18)

There was also skepticism about the accuracy of outputs because users did not understand the cost apportionment algorithms or could not directly verify the results (66:Annex B,4; 146:2). Additionally, there were expectations amongst users that VAMOSC would be a cost accounting or cost estimating system and not just a cost data repository

(147:2). Users also expected the system to have greater compatibility with CORE and other LCC models (118:71-72), and have data on a greater range of weapon systems.

There were a number of reasons for these problems and disappointments. Firstly, the Office of VAMOSC failed to give the system adequate publicity and advise potential users of its capabilities and restrictions. Also, because of delays in fielding VAMOSC, features referred to in initial user's manuals were still being refined when the baseline version of the system was made available to users. Secondly, the situation was not aided by the reluctance of users to read the manuals to enlighten themselves about VAMOSC's features (118:68,70). Thirdly, and most significantly, the CYBER-based system was beset by problems. Numerous data problems were encountered. For instance, source data files sent on magnetic tape for input into VAMOSC were often incorrect or missing complete fields. The system preprocessor, VAMOH had limited data editing capabilities. In the best case it would ignore incorrect data items, resulting in the loss of information and underreporting. In the worst case, however, the spurious data would be mishandled and invalidate subsequent calculations (117:Sec 3,8). The large volume of tapes sent in also made it difficult to check for completeness and accuracy. Wrong tapes were often sent or tapes did not arrive on schedule, thereby causing significant delays in VAMOSC quarterly runs

(117:Sec 3,8). TASC reports on one situation where the same data was sent in for six consecutive years before being detected (117:Sec 3,8-9). TASC also highlights a nomenclature problem that caused engine data from one feeder system, D042A (Comprehensive Engines Management System) to be ignored by VAMOH (117:Sec 3,11-12).

TASC notes in its report on VAMOSC that other specific data problems stemmed from incomplete, out-dated, or erroneous data dictionaries, cross reference registers, or lists which VAMOH used to select and process input data (117:Sec 3,12). The original VAMOSC was also highly inflexible owing to the fact that it had no separate, identifiable database from which to extract data to feed its costing algorithms (117:Sec 3,18). TASC indicates that the system had a convoluted structure. For example, a piece of input data may have passed simultaneously along several different paths producing multiple and varying values that all purported to represent the same information (117:Sec 3,18).

The complexity of VAMOSC also limited the ability to trace cost algorithm inputs back to their original source and substantially increased the potential for error if a programming change was necessary. TASC describes a typical situation:

> If the Air Force were to decide to alter the definition of an algorithm input, programmers would have to trace the path along which the input is passed from the feeder

system tapes, through VAMOH, through several subsequent programs and tapes, and finally into the algorithm. Then code for all these processes would have to be analyzed and possibly reworked to accommodate the change. If that input is used by other algorithms and calculations, these calculations would have to be identified, and the same tracing and reprogramming procedure repeated for each calculation. (117:Sec 4,2)

Verification and Validation Studies. Concurrent with the release of VAMOSC in 1982, the Office of VAMOSC commissioned several contractors to appraise the accuracy of the source data and allocation algorithms used by the VAMOSC subsystems; assess the degree to which user requirements were being satisfied; and, on the basis of their findings, recommend changes to the system. The task of reviewing the CSCS and C-E data subsystems was assigned to Information Spectrum Inc., and Desmatics Inc., was asked to examine WSSC.

Recktenwalt notes that the Office of VAMOSC appreciated that because VAMOSC data would be used, in part, to justify the procurement of new weapon systems and the modification of existing ones, its credibility and veracity had to be of the highest possible standard (137:10). In light of this statement, it is difficult to understand why the policy of concurrent release and validation was adopted. The problems identified by Desmatics and Information Spectrum (as detailed in the TASC report referred to above) in the three VAMOSC sub-systems undoubtedly contributed quite substantially to the lack of credibility that the VAMOSC system now suffers.

VAMOSC Modernization Program. In 1988, after taking stock of the Information Spectrum and Desmatics recommendations, the Office of VAMOSC commissioned the Analytical Sciences Corporation (TASC) to undertake a two-phase project aimed at correcting the major deficiencies noted in VAMOSC and modernizing the system (69:3). Phase one of the project involved rehosting VAMOSC at the Air Force Cost Center (AFCSTC), and phase two incorporated the redesign of VAMOSC "from a card-orientated, batch-driven system to a state-of-art integrated data base system" (69:3). Incorporated in the redesign was the replacement of the VAMOH with a much more powerful source data preprocessor. The C-E subsystem was not included in the modernization program (69:3).

After a user survey, CSCS was chosen as the first subsystem to undergo redevelopment. Notwithstanding its sound design, the modernization program was immediately impacted by funding constraints and schedule creapages. The redesigned CSCS subsystem was originally scheduled for implementation in October 1989, however, the task was not actually completed until late in 1990 (69; 140). Furthermore, it was originally intended to have a complete year's worth of CSCS cost data on-line, with another nine years available through an archival retrieval system. However, the loading of data has been slow thereby limiting the usefulness of subsystem. The redevelopment of WSSC seems destined to follow a similar

fate. The new and improved WSSC subsystem was scheduled for release in the fall of 1990. However, at the time of writing the modification effort was still in progress (140).

Traversing the Credibility Gap. Notwithstanding the promising features incorporated in the redesign of VAMOSC, and its user friendliness, the system has an enormous credibility gap to bridge if it is ever to be accepted into the DOD cost analysis community. The author found that the bitter taste of the first encounter with VAMOSC was still quite fresh in the mouths of a number of analysts.

When the revisions to VAMOSC are finally completed, an extensive advertising campaign, backed up by informative manuals and a well structured educational package, will be needed to help redeem the system in the eyes of previous users. As Desmatics noted in one of its reports on VAMOSC, for the acceptance of a system to grow it is not sufficient that it provide "accurate, complete, timely, pertinent and unbiased information"--this is assumed--it must also be perceived by its users and the cost analysis community generally to possess these attributes in good measure (118:70). From the interviews conducted by the author, the general perception of VAMOSC in the cost community at present is that the system is a "white elephant". The poor reputation of the system has spread to such an extent that even analysts who have never used the system are convinced

they will never use it, despite any improvements that might be made.

This situation is unfortunate because VAMOSC, if sufficient funding allows it to maintain its proposed specification, has the opportunity to make a significant contribution to LCC analyses. As noted previously, by far the most significant cost involved in LCC analysis in the USAF today is the manpower involved in gathering and verifying input data, particularly O&S cost information. Currently, analysts spend a great deal of time querying the very same data bases that are accessed by VAMOSC because they doubt the accuracy of VAMOSC supplied information. In order to overcome this problem the Office of VAMOSC must go to considerable lengths to explain to, and convince, potential users of VAMOSC of the reasonableness of its cost apportionment algorithms. This was one of the primary failings in the original VAMOSC release; users were unaware of the origin or basis of numerous cost equations and were unable to obtain a reasonable explanation either through consulting the user's manuals or by contacting the OPR (66:Annex B,4).

Another problem that VAMOSC faces is that it will always be judged by the quality of the data sources that it uses. The original charter for the establishment of VAMOSC mandated that the only existing Air Force data sources be used by the system. This has limited VAMOSC in a number of areas. Also

several of the data sources which VAMOSC has no choice but to use, such as the Maintenance Data Collection System (MDCS), have had their accuracy questioned in a number of studies (35; 75; 80;). Fortunately, projects such as the Logistics Management System (LMS) Modernization Program should assist in the area of data veracity and provide VAMOSC with a greater choice of primary data sources (117:Sec 3,1).

If VAMOSC is "marketed" properly and achieves widespread user acceptance, it has the potential to substantially reduce the amount of time analysts spend gathering O&S cost information and, simultaneously, increase the accuracy of estimates. Furthermore, it has considerable scope for future expansion. For instance, TASC notes that the range of systems covered could be expanded to include missiles and ground based systems. Furthermore, the system could be adapted to provide specific input for established LCC models such as CASA and LSC. TASC suggests that AFR 173-13 (Air Force Cost and Planning Factors) cost factors could also be hosted on VAMOSC (117:Sec 6,6-9).

Demand-Based Cost Estimating

An issue that is likely to gain increased prominence during the 1990s, as a result of real and anticipated cutbacks in defense spending, is "demand-based" cost estimating. This issue has significance for LCC because it

is likely that LCC models such as LSC and CASA will be used in the process.

Rationale for Approach. Recent work in the area of demand-based cost estimating in the early phases of acquisition programs has been done by Capt Anne Dement of ALD/LSS (36). Dement notes that budget estimates for weapon system cost elements such as initial spares have traditionally been developed using cost factor techniques. For instance, initial spares requirements might be estimated as a certain percentage of the flyaway cost of a new system. Dement indicates that these budget factors are derived by selecting an analogous existing weapon system and making adjustments, based on informed opinion, for the likely cost impact of new technologies, performance levels, and the operating and maintenance concepts of the system (36:1). Despite these adjustments, Dement believes, cost factor techniques are:

> very insensitive to the subtle relationships [that exist] between...requirements, system performance, and the support environment because of the aggregate level at which it [the technique] is applied and because the support environment is not explicitly considered....[and consequently] provides little visibility into the conditions driving the estimate. (36:1)

Dement emphasizes the fact that factor estimates are difficult to defend at the Air Staff and Congressional levels, "particularly in the current fiscally constrained environment" (36:1).

A demand-based estimate, as defined by Dement, is one where the quantity of interest, e.g., spares, is computed using the actual characteristics of the weapon system, such as the flying hour program, component reliabilities and maintenance concept (36:1). Dement suggests that a demand based approach "makes it easier to see the causes driving each requirement and promotes better understanding of the logistics needs" (36:1).

Dement goes on to explain why demand-based cost estimating techniques have not been used in the past during the early phases of system acquisition. The principal reason is that quite detailed information is required in order to exercise demand-based models and this type of data is generally not available until late in the acquisition cycle (36:1).

Using aircraft initial spares as an example, Dement sought to develop a methodology that could overcome the traditional data problem by using the cost factor approach of basing an estimate on an analogous weapon system (36:2). Using the F-16C as the "baseline" weapon system and employing the LSC model, she aimed to develop a budget estimate for initial spares for the Advanced Tactical Fighter (ATF) during the demonstration/validation phase (Phase I) of the system's acquisition (36:2).

Dement's demand-based estimate for the ATF was 6.3 percent higher than the SPO's Fiscal Year 1989 Annual

Estimate, which was developed using a parametric model (36:5). Dement notes that it was impossible to quantify precisely the impact of each factor contributing to the difference between the estimates owing to the fact the parametric estimate "masked the relationship between system performance and supportability parameters" (36:5). However, she suggests that:

> the small difference between the estimates was most likely due to the use of the F-16C as the baseline for one estimate and the F-15C for the other, and to the inherent errors in both estimates resulting from the use of preliminary ATF data. (36:5)

Assessment of Demand Based Technique. Dement concluded from her study that demand-based estimating could provide a reasonable initial spares estimate, even in the data constrained environment of early program acquisition (36:5). Additionally, the experiment served to highlight the advantages and disadvantages of demand-based estimating techniques.

Disadvantages. The principal disadvantage of demand-based estimating is the amount of effort required to develop a database for a new weapon system. Dement notes that obtaining detailed information on the comparable weapon system can also be quite trying, the level of effort being entirely dependent on the complexity of the analogous system "and the availability and quality of its historical data" (36:6). She notes that parametric techniques, with their focus on the major subsystem level of equipment indenture,

require significantly less data, but they mask interrelationships that exist between system performance and supportability parameters (36:6). Dement goes on to indicate that the situation could be improved by the development of a database library containing files for various weapon systems that could be used to baseline initial spares estimates on future systems. She notes that an effort in this regard is currently underway in ALD/LSS (36:6).

Advantages. Dement believes that the advantages in implementing a demand-based cost estimating approach far outweigh the disadvantages. In addition to making budget estimates more defendable, she suggests that one of the main advantages of the approach is to create "a direct tie between the budget development and provisioning approach processes" (36:6). Additionally, she believes, demand-based estimating means that the same estimating approach can be used throughout a weapon system's life cycle. Dement believes that a consistent approach across phases provides decision makers with a better understanding of how estimates are developed, which in turn should assist the defense of estimates in budgetary processes (36:6-7). Thirdly, she suggests, demand-based techniques, unlike parametric methods, allow useful trade-off studies to assess the cost impact of various R&M improvements and other logistic scenarios (36:7).

Future Developments. Dement concludes by suggesting ways in which demand-based estimating could be accommodated

in future acquisition programs. Principally, she suggests that the cause of demand-based estimating could be championed by modifying RFP information requirements to support the execution and updating of model data. She notes that while implementation of the technique appears complex, it is really just an extension of Logistics Support Analysis (LSA) requirements into the costing arena, and would be "a positive step towards standardizing the tasks to be accomplished in all acquisition programs" (36:9).

Merit of Concept. The demand-based estimating approach proposed by Dement for application during the early stages of acquisition programs is certainly worthy of further investigation.

As Dement notes, demand-based estimating has particular strengths in the area of defending budget estimates. It therefore behooves the Air Force to be proactive and investigate the technique further before the combined affect of budget cutbacks and Congressional reluctance to fund major new weapon system projects forces its adoption. However, any further investigation must include application of the technique in situations where convenient baseline systems, such as the F-16, are not available. This will be the "litmus test" of the methodology. It is well known that the F-16 project is one of the best, if not the best, defined major weapon system purchased by the Air Force in terms of documentation and data support.

Model Validation

Another issue that has recently come to the fore, because of CAIG concerns in the area, is the validation of LCC models. In 1989, a policy memorandum was issued by SAF /ACC indicating that, in future, the CAIG would not accept estimates prepared using non-validated LCC models. The memorandum indicated that the CAIG was particularly concerned about the proliferation of algorithm driven accounting type models, similar to the LSC model, because they were not generally empirically based (39). A follow-up memorandum from SAF/ACC, issued in the same year, clarified what was involved in a "validation" effort by specifying that the model developer could either cross-check a model against an another "accepted model" or validate it by running it against a reference set of actual data. The memorandum put the onus on the model developer to organize the validation effort, but stated that assistance in developing a "validation plan" could be obtained from the AFCSTC (39).

Since that time, to the best of the author's knowledge, only one model, the LSC, has been formally validated. The task was completed in May 1990 in an extensive effort undertaken by MCR Inc (1). The results of the validation effort undertaken by MCR, make it obvious that a comprehensive model evaluation is a painstaking and time consuming undertaking, and not something a model developer can conduct in his spare time. The author believes that the

reason for the slow progress on the validation issue is that the AFCSTC has been slow in issuing detailed guidance on how a validation study should be conducted. No OPR wants to organize its own validation study only to find later, when the AFCSTC finally issues guidelines, that it must repeat the effort because of problems with its methodology. In any case, independent validation is preferable to inhouse efforts because of the reduced risk of "turf" bias.

Whether validation efforts are eventually undertaken internally or externally, it is essential that detailed standard guidelines be provided. Notwithstanding the difficulty of the task, if the AFCSTC wishes to pay any more than "lip service" to the CAIG requirement it must expedite the issuance of validation guidelines and coordinate the Air Force wide validation program. The effort conducted by MCR provides a sound foundation for the undertaking.

Accurate standard data sets would also assist the effort. MCR found in its study of the LSC model that a considerable amount of their time was spent gathering and then confirming the veracity of the data set it prepared.

Expert Knowledge of LCC

The LCC Minefield. If there is one thing in particular that this study highlighted it is that LCC is not just simply a case of identifying the right LCC model for the job and plugging in the appropriate numbers. Considerable experience

is needed on the part of the analyst, firstly to identify a suitable model, and then to gather data from the variety of sources available and verify its reasonableness prior to exercising the model. Chapters three through five highlight the fact that various models are designed with particular purposes in mind, make numerous assumptions (which are not always clearly indicated in the user's manual), and have different strengths and weaknesses. Consequently, LCC can be a veritable "minefield" for the inexperienced cost analyst, and it is imperative that such persons receive detailed guidance from more experienced (battlehardened) analysts.

Current Knowledge Base. Moreover, the author found that because of the variety of LCC models available, there was no one organization in the Air Force that could be considered a repository of expert LCC knowledge. ASD/ALT and ALD/LSS, and to a lesser extent AFLC/FMC, have a substantial amount of experience using LCC models that focus on the O&S cost portion of the life cycle. Also, ASD/FMC have a corresponding amount of knowledge on acquisition LCC models. The AFCSTC provides what is essentially a referral service, putting interested parties in contact with the OPRs of various models that may be applicable to their particular situations. However, AFCSTC's level of knowledge of particular models is limited.

Implications of Formation of AFMC. In relation to establishing a core group knowledgeable in LCC, the

disbandment of AFSC and AFLC, and the formation of AFMC in July 1992 offers an ideal opportunity to take positive steps in this regard. Although final details of the alignment of the different Command LCC organizations has yet to be determined, it is likely that previously separated O&S and acquisition staff functions will be amalgamated thereby consolidating LCC knowledge within a particular area.

Contractor Involvement in LCC

The Air Force has typically employed contractors in the development of initial versions of LCC models. This was the case for LSC, LCCH, CASA, MLCC, Dyna-METRIC and LCOM. ZCORE and PRICE were exceptions to the rule. ZCORE was developed "in-house" by ASD/ALT, and the GE PRICE models are proprietary and were never handed over to the Air Force. The PRICE models are currently operated, under contract, using a time-sharing arrangement. The involvement of contractor's in model development efforts has been a mixed blessing for the Air Force on occasions. In most situations contractor's have provided much needed manpower and skill, the absence of which would otherwise have prevented the development of a model. In the case of the MLCC model, however, the poor quality of support documentation provided by the contractor has made it extremely difficult to update the parametric model's cost database. As a consequence, the MLCC model is in danger of becoming obsolete (148). On other occasions, contractor's

have deliberately made their programming codes convoluted in an attempt to ensure their continued involvement in a program if modifications should be required. This practice was more prevalent in the 1970s than 1980s, and has virtually been eliminated in the 1990s with the widespread adoption of fourth generation programming languages.

In relation to contractor participation in the day-to-day operation of the LCC models reviewed, their degree of involvement was not as extensive as originally anticipated. Klipfel advises that AFLC occasionally uses contractors to gather data for use in LSC model estimates (113). In the YW (Simulator) SPO at Wright-Patterson AFB, simulators are maintained solely using CLS and a contractor is employed to use the CASA model to assess the cost-effectiveness of various contractor support proposals. However, LCCH, MLCC, Dyna-METRIC and LCOM are operated almost totally by Air Force personnel.

Future Issues and Trends

Effect of Advanced Manufacturing Technology on LCC Estimating

The Air Force and other military services have traditionally relied on parametric estimating techniques to produce both LCC and budget estimates during the early phases of weapon system acquisitions when detailed technical specifications are not available and no historical cost data has yet been generated. Hough notes that despite its

weaknesses, the technique has proven to be particularly useful and robust for estimating the costs of new weapon systems (101:1). However, he also notes that rapid improvements in product and manufacturing process technology threaten to diminish the utility of the parametric approach. Additionally, advanced manufacturing technology (ATM) has important implication for accounting type models used to estimate weapon system acquisition costs because of its impact on "learning curves" so critical to the derivation of total costs using this methodology.

Problems with Parametrics. Parametric estimates are generally used to obtain rough order of magnitude estimates for new weapon systems. Analysts generally accomplish this task by routinely committing the "cardinal sin of regression analysis"--extrapolating beyond the range of the current data (101:2). Hough notes, however, that the major problem facing the cost analyst is finding a sufficient body of historical data in order to develop a CER (101:3). This database problem has become even more acute for Air Force analysts involved in developing aircraft CERs because fewer new generation aircraft are being built each decade and lesser quantities of each type are being procured (101:3). For example, Hough notes that the United stated procured over 6000 fighters in 1951 compared with less than 300 during 1984. Similarly, the USAF fielded six new fighters in the 1950s, but only one (the F-117) in the 1980s (101:3). Rapid

advances in product and process technologies threaten to exacerbate the data problem.

Traditional aircraft parametric models have treated cost as a function of two principal variables--size and weight. In the 1970s, with rapid advances in product technology, an attempt was made to incorporate a third major driving variable in CERs--technological advance. Various types of technology indexes were tried, some subjective in nature and others supposedly objective (115;18-28; 109:26; 116:47-48). Hough notes that given the stable manufacturing conditions that existed up until the 1980s, such models had intuitive appeal (101:4). However, he suggests, tremendous advances in manufacturing in the last decade, such as CAD/CAM and computer integrated manufacturing (CIM), "suggest that an additional variable is needed to measure the manufacturing climate" (101:4). Hough suggests that one of the reasons why costs are often underestimated is because of the inability to fully appreciate the level of technical difficulty involved in some new weapon systems (101:4). Conversely, failure to give due consideration to the production environment could lead to an overestimate of cost because military equipment can generally be manufactured cheaper using the latest machining and process technology. For instance, Stekler suggests that McDonnell Douglas could have reduced the unit production cost of the F-4 by 12.5 percent (at the 155th unit) if manufacturing technology used on the F-15 had been

available at the time (101:4-5). The inference that can be drawn from this example is that accounting for evolving manufacturing technology could significantly improve estimating accuracy.

<u>The Analyst's Dilemma</u>. Hough indicates that although several measures of technological change in military hardware exist, no aggregate measures of manufacturing technology have yet been developed. Large and Johnson suggest that attempts at including product technology indexes in CERs have not proven particularly successful to date (115:18-28; 109:26). The dilemma for the analyst then is "how to make the technology and manufacturing variables operational in a parametric context" (101:6)

AMT appears to have numerous economic benefits over traditional production plants. Hough notes that the most prominent benefits are "higher efficiencies achieved through direct labor savings, lower set-up times, and increased quality in the form of reduced scrap and rework" (101:14). Another key enhancement offered by CAD/CAM, which has particular relevance to the military, is reduced development time. Hough suggests that flexible manufacturing systems (FMS) also hold the potential of allowing variety in production without increasing unit cost (101:14). However he notes that "the ability to directly measure the savings associated with implementing AMT tends to decrease as the firm moves to higher levels of automation" (101:15).

(101:18). Hough notes that the changing manufacturing environment presents a double-edged sword to the analyst. "Traditional cost systems may not reflect true product costs, and new cost systems may diminish or even eliminate the utility of older databases" (101:19).

Flatter Learning Curves. The use of AMT is also expected to impact the application of learning curve theory in cost estimating. Hough notes that there is disagreement amongst analysts as to the likely consequences of the application of AMT and further research is needed in the area. Some researchers suggest that AMT will reduce the opportunities available for workers to learn better ways to accomplish a task, primarily due to the overall reduction in direct labor and tasks under AMT. As a consequence, they predict that the learning curve will be much flatter and the standard cost point (the quantity at which no further learning takes place) may fall to less than 100 units by the year 2000. Other researchers argue that with fewer workers in the AMT factories of the future each worker will have greater control over the process meaning that the learning curve will be sharp initially but flatten out very early in a production run (101:21).

Implications for Cost Analysts. Analysts need to be aware that with increased numbers of firms now using or investing in AMT there is an increased risk of "deriving estimates based on outdated manufacturing methods" (101:26).

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While no definitive methodology has yet been developed to allow the incorporation of process technology in estimates, analysts should be aware of potential trends caused by the phenomenon and adopt a questioning attitude in their dealings with contractors. More specifically, it is particularly important that the analyst attempt to make an assessment of a potential contractor's current state of implementation of AMT and ascertain the nature of future AMT development plans. Hough suggests that analysts using parametric models may also wish to experiment and "repeat previous cost regressions with the addition of a manufacturing index" (101:26).

There can be little doubt that AMT has serious implications for defence contracting and estimating techniques. Further research is desperately needed in the area if government cost analysts are to retain their ability to accurately predict costs and validate contractor proposals.

Risk Analysis Capabilities

LCC and budget estimates have traditionally been presented to decision makers in the Air Force and DOD as point estimates. With fewer weapon systems, particularly aircraft, now being developed each decade because of higher unit production costs and, more recently, the downsizing of the defense budget, there is inherently greater risk involved in each major program undertaken. This risk is magnified in

most cases by the quantum leap in product technology represented by proposed systems, when compared to their predecessors, and also because of advances in manufacturing process technology. As a result of these uncertainties, it has become particularly important that estimating tools, especially LCC models, have the capability to incorporate risk analysis.

While the most recent versions of a number of the LCC models reviewed by the author incorporated quite extensive sensitivity analysis capabilities, only CASA makes specific provision for risk analysis. It is essential that decision makers be given information on the most pessimistic, most likely, and the most optimistic costing eventualities if they are to make rational and informed choices amongst alternatives.

Integration of LCC Models

During the course of conducting the review of the LCC models detailed in chapters three through five, it became apparent to the author that considerable scope existed to integrate the inputs and outputs of various models. At present, LCC models tend to be operated in isolation to fulfil the needs of cost analysts. The only exception to this rule is where outputs from models such as the LSC and LCOM are used to feed the Air Force's standard cost factor model, CORE or its computerized equivalent, ZCORE.

However, a number of other opportunities for model integration exist. For example, LCOM is usually operated by arbitrarily selecting levels for spares and other logistics resources, and sequentially varying maintenance manpower levels until a point is reached when one unit of manpower can be withdrawn without the aircraft availability measure falling below the established threshold. LCOM's starting position could be improved considerably, for instance, by using Dyna-METRIC in its requirements computation mode to generate an optimal spare parts list, for a specified weapon system availability objective, and then inputing this information to LCOM. Similarly, cost element deficiencies in otherwise strong models could be supplemented by using information from other LCC models with strong algorithms in those particular areas.

Use of Expert Systems

As mentioned previously, one of the problems faced by the Air Force in conducting LCC analyses is the general lack of experience among cost analysts. Although the most recent versions of the models reviewed by the author are quite user friendly and a number have on-line help facilities, they do not provide assistance with the actual conduct of an LCC analysis. However, expert systems offer the potential to fill this gap. An expert system could be used as a "front-end" for a LCC model to provide an inexperienced cost analyst

with information on how the model operates, explain particular algorithms and, based on user input regarding the type of analysis to be conducted, help identify potential sources of cost information. Similarly, expert systems could also be tailored to act as LCC model post processors in order to help analysts interpret output results.

The work involved in setting up such an expert system would be quite extensive, and an OPR would need to make sure that the LCC model was validated before such an effort could be justified.

Conclusion

It is readily apparent from this study that a number of improvements have been made in LCC models since the time of the JCWG and Rand studies in the 1970s. For instance, models now tend to have a more standard cost element structure, they are generally PC based making them more readily accessible to cost analysts, and user friendliness has improved significantly. Furthermore, there are now parametric models available, such as PRICE and MLCC, that can be used to relate weapon system design characteristics to cost early in the concept exploration and design phase of a weapon system, and the algorithms used in accounting models, such as the LSC, more closely correspond to the nature of the systems they model.

The status of LCC has also been improved during the intervening period by the promulgation of directives such as DODD 5000.45 (Baselining of Major Weapon Systems), the requirement to conduct COEAs at major program milestones, and the revision of DODD 5000.1 (DOD Acquisition Process). In essence, LCC became institutionalized within the DOD during the 1980s.

Notwithstanding these improvements, a number of challenges remain for LCC in the 1990s. The most pressing of these problems is the data collection problem caused by the data intensity of the current crop of LCC models. With drawdowns in defense expenditure occurring there will undoubtedly be greater competition for weapon system starts. It will, more than likely, mean that earlier and more detailed justification, particularly costing information, will be needed to convince Congress of the wisdom of DOD procurements. Consequently, it is unlikely that the data intensity problem will diminish. In light of this, the Air Force must find ways to streamline the LCC data gathering process. The revised VAMOSC system offers considerable scope for improvement in this area, but it must be validated and publicized properly, prior to release, if it is to avoid the problems of the earlier version. However, to realize these improvements, the Air Force must resist the temptation to cut expenditure on the VAMOSC upgrade program.

A number of other challenges also face LCC in the future. These challenges include the need to accommodate the affect of advanced manufacturing technology (AMT) in LCC estimates; resolve the model validation issue; and incorporate exciting new technology, such as expert systems, in models to improve the productivity of cost analysts. In this way, LCC will ensure that it remains an equal partner with schedule and performance in future weapon system acquisition projects.

Appendix A: Explanation of Terms

Base Level Self-Sufficiency Spares (BLSS). WRM spares and repair parts intended for use as base support for units which plan to operate in-place during wartime considering the available maintenance capability. BLSS represents the difference between the Peacetime Operating Stock levels expected to be available at the unit in wartime and its total wartime requirement for a specified period of time. (13:102)

Base-Year Dollars. Dollars expressed in their value at the time of the specified base year of a program, as if they were all expended during that year. Base year is a point of reference representing a fixed price level, usually defined as the fiscal year of initial funding on a program. (13:102)

Class IV Modification (MOD). A permanent modification for safety, material deficiencies, or to improve reliability and maintainability. (13:102)

Condemnation. An item that is nolonger reparable. (13:102)

Cost Estimating Relationship. A mathematical relationship that defines cost as a function of one or more parameters such as performance, operating characteristics, or physical characteristics. (13:102)

Depot Level Maintenance. The level consisting of those on- and off-equipment tasks performed using the highly specialized skills, sophisticated shop equipment, or special facilities of a supporting command; commercial activity; or interservice agency at a technology repair center, centralized repair facility or, in some cases, at an operating location. Maintenance performed at a depot also includes organizational or intermediate level maintenance as negotiated between operating and supporting commands. (13:103)

Constant-Year Dollars. Dollars expressed in their value at the time of any specified year, which may, but does not have to be, the base year. Also called constant dollars. (13:103)

Cost Driver. A cost element that contributes substantially to total system LCC.

Cost Effectiveness. Cost effectiveness is a comparative term used to measure a system's technical performance or mission capability against its total LCC. (8:19)

Then-Year Dollars. Constant or base year dollars deflated or inflated through the use of indices to show the total amount of money needed to buy goods and services at the time expenditures are actually incurred. (13:103)

Integrated Logistics Support (ILS). ILS is a disciplined, unified, and iterative approach to the management and technical activities necessary to: (1) integrate support considerations into system and equipment design; (2) develop support requirements that are related consistently to readiness objectives, to design and to each other; (3) acquire the required support; (4) provide the required support during the operational phase at a minimum cost. (13:104)

Intermediate Level (I-Level) Maintenance. The level consisting of off-equipment tasks normally performed using the resources of the operating command at an operating location or at a centralized intermediate repair facility. Off-equipment maintenance refers to those maintenance tasks that are not, or cannot be, effectively accomplished on or at the weapon system or end-item of equipment, but require the removal of the component to a shop or facility for repair. (13:105)

Life Cycle Cost Analysis (LCCA). A systematic analytical process of evaluating various courses of action with the objective of choosing the best way to employ scarce resources. (7:11) LCC is employed in evaluating alternative design configurations and LCC "figures of merit" are used as criteria in arriving at a cost effective solution. (8:369)

Line Replaceable Unit (LRU). An essential support item which is removed and replaced at field level to restore the end-item to an operationally ready condition. (13:105)

Logistics Support Analysis (LSA). The selective application of scientific and engineering efforts undertaken during the acquisition process, as part of the system engineering and design process, to assist in complying with supportability and other ILS objectives. (46:Ch 5,10)

Logistics Support Analysis Record (LSAR). LSAR is the data which documents the detailed engineering and support requirements data generated by the LSA process. Standard requirements, data element definitions, and LSAR data record formats are prescribed in MIL-STD-1388-2A. (13:105)

Maintainability. An inherent characteristic of a system's design which pertains to its ability to be retained in, or

restored to, a specified condition when maintenance is performed. (46:Ch 11,1)

Mean Time Between Demand (MTBD). A measure of the system reliability parameter related to demand for logistics support. It is calculated by dividing the total number of system life units (usually hours) by the total by the total number of item demands on the supply system during a stated period of time. (13:105)

Mean Time Between Failure (MTBF). The basic measure of reliability for repairable items. It is calculated as the mean number of life units (usually hours) during which all parts of an item perform within their specified limits, during a particular measurement interval under stated conditions. (13:105)

Mean Time Between Removal (MTBR). Is a measure of expected maintenance actions. It is calculated as the mean number of life units (usually hours) before an item is removed from a system because of a suspected failure. (93:Att 5,3)

Model. A simplified representation of the real world which abstracts certain features of the situation relevant to the problem being analyzed. (7:81)

Organizational Level (O-Level) Maintenance. The level consisting of those on-equipment tasks normally performed using the resources of the operating command at an operating location. On-equipment maintenance refers to those maintenance tasks that are, or can be, effectively performed on or at the weapon system or end-item of equipment. (13:106)

Parametric Cost Estimate. A cost estimating methodology using statistical relationships between historical costs and other program variables such as system physical or performance characteristics, contractor output, or manpower loading. Also referred to as a "top-down" approach. (13:106)

Peacetime Operating Stock (POS). Stock that supports the peacetime objectives of the Air Force, i.e., to train combat forces, support day-to-day operations and ensure that weapon systems are ready to perform their wartime mission. (13:106)

Pipeline. In logistics, the channel of support or a significant portion thereof by means of which materiel or personnel flow from sources of procurement to their point of use. (13:106)

Reliability. The probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating conditions. (8:12)

Shop Replaceable Unit (SRU). Equipment items normally identified as defective and replaced at the intermediate level shop, then sent to the depot for further disposition. At the depot, unserviceable SRUs are either fixed and returned to the supply system, or condemned and sold or scrapped. (13:107)

Sortie. An operational flight by one aircraft. (13:107)

Through-Life Cost. The costs associated with the operation and maintenance support of a system throughout its life cycle subsequent to equipment delivery to the field, plus the cost of equipment phase-out and disposal (8:19)

War Readiness Spares Kit (WRSK). An air transportable package of war readiness material spares, repair parts, and related maintenance supplies required to support planned wartime or contingency operations of weapon or support systems for a specified period of time pending resupply. (13:107)

Work Breakdown Structure (WBS). A product-oriented family tree composed of hardware, services and data which results from project engineering efforts during the development and production of a defense material item, and which completely defines the project/program. The WBS displays and defines the product(s) to be developed or produced, and relates the elements of work to be accomplished to each other and to the end product. (13:108)

Appendix B: Glossary of Acronyms

AAM	- Aircraft Availability Model.
ADS	- Automatic Data System.
AFCC	- Air Force Communications Command.
AFCSTC	- Air Force Cost Center (now Air Force Cost Analysis Agency)
AFHRL	- Air Force Human Resources Laboratory.
AFLC	- Air Force Logistics Command.
AFMEA	- Air Force Manpower Engineering Agency.
AFMSMET	- Air Force Maintenance, Supply, and Management Engineering Team.
AFMSMMET	- Air Force Maintenance, Supply, Manpower, and Munitions Engineering Team.
AFS	- Air Force Specialty.
AFSC	- Air Force Systems Command.
AFTEC	- Air Force Test and Evaluation Center.
AGE	- Aerospace Ground Equipment.
ALD	- Acquisition Logistics Division.
AMT	- Advanced Manufacturing Technology.
AMTAF	- All Mobile Tactical Air Forces (Model).
ASD	- Aeronautical Systems Division.
ASM	- Aircraft Sustainability Model.
AWP	- Awaiting Parts.
CAIG	- Cost Analysis Improvement Group.
CAMS	- Core Automated Maintenance System.
CARRS	- Cost Analysis Resource Reference System.

CASA	- Cost Analysis and Strategy Assessment (Model).
CERs	- Cost estimating Relationships.
CES	- Cost Element Structure.
CLS	- Contractor Logistics Support.
COA	- Calculated Operational Availability.
COEA	- Cost and Operational Effectiveness Analysis.
CCRE	- Cost Orientated Resource Estimating (Model).
DAB	- Defense Acquisition Board.
DAE	- Defense Acquisition Executive.
DMAS	- Dyna-METRIC Micro-computer Analysis System.
DOD	- Department of Defense.
DRCT	- Depot Repair Cycle Time.
Dyna-METRIC	- Dynamic Multi-Echelon Technique for Recoverable Item Control.
ECP	- Engineering Change Proposal.
FMOD	- Fill Rate During Resupply
ICA	- Independent Cost Analysis.
ILS	- Integrated Logistics Support.
JCWG	- Joint AFSC/AFLC Commanders' Working Group on LCC.
LCC	- Life Cycle Cost.
LCCH	- Life Cycle Cost H (Model).
LCOM	- Logistics Composite Model.
LMI	- Logistics Management Institute.
LRU	- Line Replaceable Unit.
LSA	- Logistics Support Analysis
LSAR	- Logistics Support Analysis Record.

LSC	- Logistics Support Cost (Model).
MAC	- Military Airlift Command.
MAJCOM	- Major Command.
MCR	- Management Consulting and Research.
MDCS	- Maintenance Data Collection System.
MDS	- Mission design Series.
MDT	- Mean Down Time.
MINDM	- Minature Dyna-METRIC.
MLCC	- Modular Life Cycle Cost (Model).
MNS	- Mission Need Statement.
MSBMA	- Mean Sorties Between Maintenance Actions.
MTBD	- Mean Time Between Demends.
MTBF	- Mean Time Between Failure.
MTBM	- Mean Time Between Maintenance.
MTBR	- Mean Time Between Removal.
MTTR	- Mean Time To Repair.
NRTS	- Not Repairable This Station.
NRU	- Number of Replaceable Units.
NSN	- National Stock Number.
O&S	- Operations and Support.
OOP	- Out of Production.
PAA	- Primary Authorized Aircraft.
PACAF	- Pacific Air Force.
PC	- Personal Computer.
PEO	- Program Executive Officer.
PM	- Program Manager.

PRICE	- Parametric Review of Information for Cost Estimating (Models).
PSR	- Performance Summary Report.
R&M	- Reliability and Maintainability.
RAM	- Reliability, Availability, and Maintainability.
RDT&E	- Research, Development, Test, and Evaluation.
RLA	- Repair Level Analysis.
RTOK	- Retest Okay.
SAC	- Strategic Air Command.
SAE	- Service Acquisition Executive.
SPM	- System Program Manager.
SPO	- System Program Office.
SRU	- Shop Replaceable Unit.
SRUFACs	- SRU Factors.
TAC	- Tactical Air Command.
TDT	- Second Destination Transport.
TSAR	- Theater Simulation of Air Base Resources (Model).
VAMOSC	- Visibility and Management of Operating and Support Costs.
USAFE	- United States Air Force Europe.
WBS	- Work Breakdown Structure.
WSCRS	- Weapon System Cost Retrieval System.
WUC	- Work Unit Code.
ZCORE	- Z-Basic Version of CORE.

Appendix C: LCC Model Proponents

1. The Logistics Support Cost (LSC) Model:

   Headquarters Air Force Logistics Command
   AFLC/FMCC (Mr Steve Klipfel)
   Wright-Patterson AFB OH 45433-5001
   AV 787-3165, Comm (513) 257-3165

2. The Life Cycle Cost H (LCCH) Model:

   Air Force Acquisition Logistics Division
   ALD/LSS (Mr John Huff)
   Wright-Patterson AFB OH 45433-5000
   AV 785-2122, Comm (513) 255-2122

3. ZBASIC Cost Orientated Resource Estimating (ZCORE) Model:

   Air Force Aeronautical Systems Division
   ASD/ALTB (Mr Fred Conway)
   Wright-Patterson AFB OH 45433-6503
   AV 785-6551, Comm (513) 255-6551

4. Cost Analysis and Strategy Assessment (CASA) Model:

   The Defense Systems Management College
   DSMC/DRI-S (Ms Helen Haltzel)
   Fort Belvior VA 22060-5426
   AV 354-5783, Comm (703) 780-1850

5. Parametric Review of Information for Costing and Evaluation (PRICE) Models:

   Air Force Aeronautical Systems Division
   ASD/FMC (Ms Sharee Baldwin)
   Wright-Patterson AFB OH 45433-6238
   AV 785-6347, Comm (513) 255-6347

6. Modular Life Cycle Cost (MLCC) Model:

   Air Force Wright Laboratories
   WL/XPA (Mr Greg Staley)
   Wright-Patterson AFB OH 45433-6523
   AV 785-1551, Comm (513) 255-1551

7. Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) Model:

Headquarters Air Force Logistics Command
AFLC/XPSA (Ms Barbara Wieland)
Wright-Patterson AFB OH 45433-5001
AV 787-6920, Comm (513) 257-6920

8. Logistics Composite Model (LCOM):

Air Force Aeronautical Systems Division
ASD/ENSSC (Mr Dick Cronk)
Wright-Patterson AFB OH 45433-6503
AV 785-8059, Comm (513) 255-8059

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Vita

Flight Lieutenant Mark G. Twomey was born on 11 December 1962 in Dubbo, New South Wales, Australia. He completed his secondary education at Dubbo High School in November 1980 and joined the Royal Australian Air Force (RAAF) as a Business Studies Cadet in January 1981. Upon graduation from the Darling Downs Institute of Advanced Education, in December 1983, he received the degree of Bachelor of Business in Operations Management and was commissioned as an officer of the RAAF. Since commissioning, he has been employed in a variety of supply duties, including four years as a barracks, catering and housing officer at No. 1 Central Ammunition Depot RAAF Orchard Hills, New South Wales. He was transferred to RAAF Base Fairbairn, Canberra, in January 1988, where he served as Stores Accounting Officer for a period of two and a half years before being assigned to the School of Systems and Logistics, Air Force Institute of Technology (AFIT), in June 1990. Following graduation from AFIT, he will return to employment with the RAAF in Australia.

Permanent Address: 23 Norfolk Crescent
Dubbo, New South Wales
Australia, 2830

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13. ABSTRACT *(Maximum 200 words)*

This study examined the history of the development of life cycle costing (LCC) in the DOD and USAF, and reviewed 11 "mainstream" LCC models currently being used by the Air Force, including the LSC, LCCH, ZCORE, PRICE H, PRICE HL, PRICE M, PRICE S, MLCC, Dyna-METRIC, and LCOM models. A literature search revealed that the last comprehensive reviews of LCC modeling in the USAF were conducted by the Joint AFSC/AFLC Commanders' Working Group on LCC and Rand in the 1970s. LCCs initial development, in the 1960s, was prompted by rapid increases in operating and support (O&S) costs as a percentage of the DOD budget. However, despite regulatory efforts, LCC did not gain equal status with schedule and performance in DOD acquisition programs until the 1980s. The review of LCC models revealed that a number of problems identified by earlier researchers still exist, particularly in the areas of data availability and validity. The study also highlighted a number of challenges facing LCC modeling in the 1990s, including the need to cope with advances in manufacturing technology, adapt to demand based estimating requirements, integrate the application of LCC models, incorporate expert systems, and establish model validation criteria.

14. SUBJECT TERMS

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